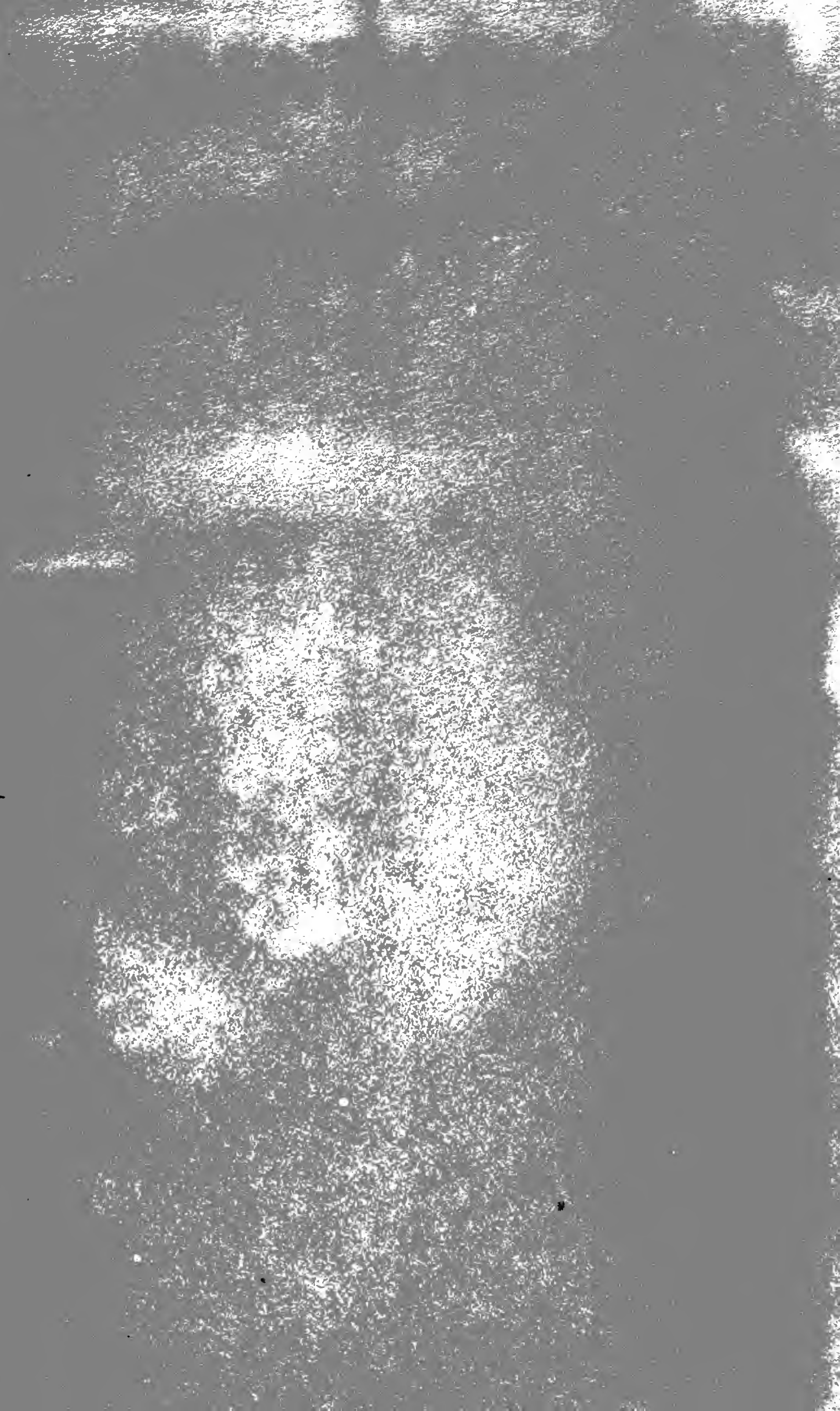
Basal Metabolic Rate Determinations

BOOTHBY - SANDIFORD



Laboratory Manual of the Technic of Basal Metabolic Rate Determinations

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PREFACE

New methods of precision for the study of disease are continuously passing from the purely scientific to the more practical clinical application. The most recent of these methods of precision and probably the most difficult technically is indirect calorimetry. This manual has been prepared in the effort to render this valuable diagnostic method available to any well-equipped and scientifically conducted clinical laboratory, and with the hope that the results of indirect calorimetry will not be thrown into general discredit by a neglect of the details requisite for obtaining a true basal metabolic rate.

Rochester, Minnesota.
August, 1920.

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TECHNIC OF BASAL METABOLIC RATE DETERMINATIONS

SECTION I

GENERAL DISCUSSION

1. **Basal Metabolic Rate.**—"In each mammal there is a basal metabolism."[55] By the term "basal metabolism" or "basal metabolic rate" of an organism is meant the minimal heat production of that organism, measured from twelve to eighteen hours after the ingestion of food and with the organism at complete muscular rest. This minimal heat production may be determined directly by actual measurement by means of a calorimeter, or indirectly by calculating the heat production from an analysis of the end-products which result from oxidation within the organism, or specifically from the amount of oxygen used and the corresponding amount of carbon dioxid produced, together with the total nitrogen eliminated in the urine.

The physiologic importance of oxygen for the needs of the body was recognized by Lavoisier (1780), who identified and named the gas. It is remarkable how clear was his conception of the problem of animal combustion both qualitatively and quantitatively. He determined the oxygen requirement with the subject fasting both at rest and at work, and also carried on experiments on the effect of food ingestion, showing that the oxidative processes within the body were thereby increased.

It was not until 1850 that serious attempts were made to advance the work of Lavoisier. At this time Regnault and Reiset

devised an apparatus for the measurement of the respiratory exchange, that is, the amount of oxygen absorbed by the subject and the simultaneous determination of the carbon dioxid produced. The apparatus was of the closed-circuit type, in which the subject rebreathed air from a closed system from which the carbon dioxid produced was removed by absorption in potash solution and the oxygen consumed was replaced as it was used by a known amount of oxygen.

A respiration apparatus which measured only the amount of carbon dioxid produced was constructed by Pettenkofer in 1862, under Carl Voit's direction. The latter, using the heat values determined in his laboratory by Rubner for protein, fat, and carbohydrate, calculated the quantity of heat arising from the burning of these substances within the body, thus developing the method of indirect calorimetry.

Rubner in 1894 constructed the first successful respiration calorimeter for experimental work on dogs. In connection with the calorimeter he used the respiration apparatus of Pettenkofer and Voit, and so was able to show the agreement between the methods of direct and indirect calorimetry, and to prove that the law of conservation of energy holds for the living organism.

In 1894 the United States Government began a series of investigations on problems of nutrition. Funds were granted by our government to Professor Atwater, of Wesleyan University, who had been associated with Voit for a number of years, and in 1897 an account of the Atwater-Rosa respiration calorimeter was published. The respiration apparatus of Pettenkofer and Voit was used in connection with the calorimeter, so that it was possible to determine on man the carbon dioxid production together with the actual heat elimination.

Later the Carnegie Institute granted a fund to Atwater for the perfection of the apparatus, and in 1905 the Atwater-Benedict

respiration calorimeter for the simultaneous determination of the heat elimination, carbon dioxid production, and oxygen absorption of a subject was completed. The accurate measurement of the oxygen absorption was an important improvement, for it was now possible to apportion accurately the quantity of oxygen used for the combustion of protein, fat, and carbohydrate if, in addition, the urinary nitrogen were determined.

As a result of another generous grant of funds from the Carnegie Institute the Carnegie Nutrition Laboratory was built in Boston, and Professor Francis G. Benedict, then of Wesleyan University, was placed in charge. Under his direction careful investigations have been made of the accuracy of the various types of respiration apparatus,[14, 29] and the respiration calorimeter was improved still further. Moreover, many fundamental problems in nutrition have been worked out in this laboratory in the greatest detail and with the highest degree of accuracy. The studies on prolonged fasting[11] and on restricted diet,[21] the investigations on the metabolism of normal persons,[15, 19] of infants,[25] and of diabetics[20] are particularly valuable.

Professor Graham Lusk, with the aid of Dr. H. B. Williams, in 1912 constructed a small respiration calorimeter at Cornell Medical College for the investigation on dogs (and on infants) of various metabolic problems. The results of this work were published by Lusk and his co-workers in a series of papers on Animal Calorimetry.[53] This great contribution by Lusk has done much to clear up many fundamental problems and to stimulate and direct along definite lines further researches on metabolism.

Lusk and Du Bois and their co-workers in 1915 began the publication of a series of papers on Clinical Calorimetry,[54] having constructed, through funds from the Russell Sage Institute of Pathology, a respiration calorimeter at Bellevue Hospital, New York, with Dr. Eugene Du Bois as medical director.[67] In these papers

they showed definitely the close agreement between direct and indirect calorimetry in the normal as well as in all the pathologic conditions investigated by them.

2. **Normal Standards.**—A very important contribution was made by Du Bois in determining the heat production in normal controls. Rubner[69] had suggested that the heat production of an individual was proportional to his surface area. For the determination of the surface area Meeh proposed the formula:

$$\text{Surface area (sq. cm.)} = 12.3 \text{ (a constant)} \times \text{weight (gm.)}^{\frac{2}{3}}$$

However, using the surface area obtained by this formula as a basis of comparison, the heat production of normal controls still showed quite wide variations, although not as great as when compared on the basis of weight alone. By exact measurements of the surface area of several bodies Du Bois demonstrated an error in the above formula due in greater part to the fact that the height of the subject was neglected.[34, 40] As a result of further studies Eugene F. Du Bois and Delafield Du Bois[35, 70] devised a formula based on height and weight by means of which the surface area can be calculated with an average error of 1.7 per cent. This formula is

$$A = W^{0.425} \times H^{0.725} \times 71.84$$

where A is the surface area in square centimeters, W is the weight in kilograms, and H is the height in centimeters, and 71.84 is a constant. On the basis of this formula they[34] then constructed a height-weight chart by means of which the surface area can be estimated at a glance. Du Bois, using this new height-weight chart for the determination of the surface area in conjunction with his standards of normal basal metabolism for age and sex,[4, 36, 40, 63] further showed that the metabolism of normal persons could be predicted with an accuracy of ± 10 per cent. This fact has been confirmed both by Means and by Boothby.

Benedict has severely criticized the method of predicting the heat

production from the unit of surface area, maintaining "that the metabolism or heat output of the human body even at rest does not depend on Newton's law of cooling and, therefore, is not proportional to the body surface."[8] Harris and Benedict in a very exhaustive treatise have reconsidered the entire problem of the prediction of the normal basal metabolic rate, and show that by proper biometric formulas, based on stature, body weight, sex, and age (the same factors as used by Du Bois), "results as good as or better than those obtainable from the constant of basal metabolism per square meter of body surface can be obtained by biometric formulas involving no assumption concerning the derivation of surface area, but based on direct physical measurements." Since their publication we have not had time to study in detail the accuracy of the two methods of prediction. We have, however, tabulated 404 determinations of the basal metabolic rate expressed in percentages above and below normal, using both the standards of Du Bois and of Harris and Benedict. The average rates of all the cases show that the rates obtained by Harris and Benedict's method are 6.5 points higher than those obtained by Du Bois' method. The parallelism between the results obtained by the two methods is strikingly shown in Table 1, in which it is seen that 195 of the 404 determinations are within ± 2.5 of the average variation. Only 52

TABLE 1. COMPARISON OF METABOLIC RATES OBTAINED BY HARRIS' AND BENEDICT'S METHOD WITH THOSE OBTAINED BY DU BOIS' METHOD

Difference between Harris' and Benedict's rates from Du Bois' rates as standard	Number of determinations for each range
-10 to -6	3
- 5 to -1	20
0 to +3	88
+ 4 to +9	195*
+10 to +14	69
+15 to +19	24
+20 to +25	5
Average of 404 determinations +6.5	
*within ±2.5 of this average	

of the entire 404 rates deviate more than 7.5 from the average variation. The comparative agreement, therefore, of the two methods is very satisfactory, indicating as it does the similarity of both methods of comparison, and supporting in a large proportion of the cases the clinical conclusions based on the Du Bois and Du Bois height-weight chart and the Du Bois normal standards for comparison.

The fact that the metabolic rate decreases with progressive inanition, as in Benedict's thirty-day fasting man, and in prolonged restricted diet is, in our opinion, an argument in favor of the clinical value of a knowledge of the heat production. The conditions cited by Benedict are abnormal and the data presented both from the metabolic and clinical viewpoint substantiate observations (not yet published) made by us that a decrease in the metabolic rate occurs in certain types of undernutrition. Such conditions cannot be considered normal either by the clinician or the physiologist, and therefore cannot be rightly used as an argument against the validity of a proposed standard of normality.

Nevertheless, Benedict's[13] statement that "There is no inflexible standard for normal metabolism for any given age, weight, height, and sex, from which all normal individuals never vary," is true. It would also be true if applied to other physiologic data of clinical value commonly determined, such as the temperature,[15] the systolic and diastolic blood-pressure, the pulse-rate, the acuity of hearing and vision, and the like. For instance, in the evaluation of the temperature clinicians are rarely concerned by variable readings between 97° and 99° F. Yet, they properly consider an elevation above 99° F. as indicative of febrile disease, usually of a bacterial character, in spite of the fact that occasionally normal and healthy people have temperatures, under certain conditions, of over 99° F.

During the past three years we have made more than 10,000

metabolic rate determinations both on healthy people and on patients suffering from various diseases. Our results will be reported in detail elsewhere, but it is in place here to state that only occasionally have we found patients who had metabolic rates beyond the normal limits established by Du Bois which could not be accounted for by the presence of a definite pathologic condition. Furthermore, we are convinced that certain pathologic conditions always produce characteristic variations in the metabolic rate and, in addition, that there is a much larger group of diseases in which there is no abnormal variation in the heat production, just as there are many diseases which have a normal temperature. We consider, therefore, that the metabolic rate differentiates with exactness three clinically characteristic groups of cases: (1) those with increased rates, (2) those with normal rates, and (3) those with decreased metabolic rates, just as surely and just as definitely as the thermometer divides diseases into the febrile and afebrile groups.

3. **Clinical Calorimetry.**—As a result of the work briefly outlined above the extended use of indirect calorimetry in clinical practice has been rendered feasible. In the clinic of Professor Edsall, at the Massachusetts General Hospital in Boston, Means and his associates,[31, 44, 57, 58, 59, 60] using Benedict's unit apparatus, investigated the metabolism in various pathologic conditions and in normal controls. At the Peter Bent Brigham Hospital, Boston, in the clinic of Professor Harvey Cushing, metabolism studies were begun in 1914 by Boothby and Sandiford, using the gasometer method originally introduced by Tissot in 1904. Both normal and various pathologic conditions were studied,[27] but most important were the investigations of the metabolic findings in disorders of the pituitary gland, publication of which has been delayed by the war.

In March, 1917 a metabolism laboratory was opened at the Mayo Clinic by Boothby and Sandiford under the clinical direction

of Professor Henry S. Plummer. In the treatment of the large number of thyroid cases seen at the clinic our results have definitely shown how essential is the knowledge of the basal metabolic rate in pathologic conditions of the thyroid. It is as essential as a knowledge of the temperature in febrile cases. With the wide-spread recognition of the importance of the basal metabolic rate in thyroid disorders it seems advisable, for the benefit of the clinician and surgeon, to give briefly a description of the methods of direct and indirect calorimetry, of the various kinds of apparatus used in indirect calorimetry, and finally to give in detail a description of the apparatus and technic used in our laboratory for the routine determination of the basal metabolic rate.

4. **Direct and Indirect Calorimetry. The Respiration Calorimeter.**—In the combined method of direct and indirect calorimetry the production and elimination of heat are determined by means of a respiration calorimeter[54] which may be defined as "an apparatus designed for the measurement of the gaseous exchange between a living organism and the atmosphere which surrounds it and the simultaneous measurement of the quantity of heat produced by that organism."[55] A complete respiration calorimeter, therefore, combines within one apparatus two separate and entirely distinct methods: the one determining the heat production and the other, the heat elimination, thus allowing a comparison of the two principles.

Heat is eliminated from the body in two ways: first, by evaporation of water from the lungs and skin, and second, by radiation and conduction. The amount of water of evaporation is determined by passing the air in the calorimeter, in which the subject is at rest, through weighed sulphuric acid—the gain in weight of the acid is the weight of this water. Since 1 gram of vaporized water contains as latent heat 0.586 cal., the gain in weight of the sulphuric acid multiplied by this factor is the amount of heat lost

by evaporation of water—approximately one-fourth of the total heat elimination.

The calorimeter itself measures the heat given off from the body by radiation and conduction. The apparatus is so constructed that there is no heat loss through the walls of the calorimeter, and consequently, to prevent the temperature within the chamber from rising to that of the body, a continuous stream of water is kept circulating through copper pipes within the calorimeter; by this means the heat eliminated from the body by radiation and conduction is removed and its amount calculated by multiplying the total quantity of water passed through the calorimeter during the test by the difference in temperature (measured to 0.01° C. by electric resistance thermometers) between the outgoing and the incoming streams of water. The heat thus calculated is subject to correction, however, if the temperature of the subject changes during the test, or if the temperature of the wall of the calorimeter varies. The measurement by the calorimeter of the heat eliminated by radiation and conduction together with the measurement of the heat eliminated by evaporation of water from the lungs and skin constitutes the method of direct calorimetry.

In connection with the calorimeter a respiration apparatus of the Benedict "unit,"[6] or closed-circuit type (more fully described below), is used to determine the respiratory exchange, that is, the oxygen absorbed and the carbon dioxid produced by the subject in a known time. From these two factors, together with the amount of nitrogen eliminated in the urine, it is possible to calculate not only the heat production but also to apportion the amount of oxygen used for the burning of protein, fat, and carbohydrate in the body. This is the method of indirect calorimetry.

The respiration calorimeter requires the full attention of at least three skilled observers, and with the constant repair and checking of the apparatus and the long preliminary and experimental

periods each of at least one hour's duration it can readily be seen that the combined method of direct and indirect calorimetry is quite beyond extensive clinical use, and, moreover, of the two methods, the indirect is to be preferred, since it is less complicated than the direct. It was necessary, however, first to determine the agreement between the two methods in normal and in pathologic conditions before indirect calorimetry could be used to measure heat production.

5. **Agreement of Direct and Indirect Calorimetry.**—Rubner showed the agreement between direct and indirect calorimetry on dogs for long periods and Lusk[53] for short hourly periods; Atwater and Benedict demonstrated this for man at rest and at work, and Howland for babies both normal and atrophic. Lusk and Du Bois[54] have shown the close agreement between the two methods in normal and in all pathologic conditions investigated by them, and have pointed out the difficulties involved in the direct method and of the comparative simplicity of the indirect. Gephart and Du Bois[39] conclude that, because of the many possible sources of error in direct calorimetry, especially in short or isolated experiments, "it is more desirable to use the method of indirect calorimetry as the standard, and to check its accuracy by the level of the respiratory quotient and the agreement with the direct calorimetry."

6. **Indirect Calorimetry.**—Krogh, of Copenhagen, and Carpenter, of the Carnegie Nutrition Laboratory, have described and compared in great detail the various kinds of respiration apparatus used in indirect calorimetry. Carpenter has shown that for indirect determinations two types of apparatus are suitable—the closed circuit and the gasometer.

(*a*) *Unit Apparatus.*—By far the best apparatus of the closed-circuit type is the Benedict unit apparatus.[6] By means of a mask, mouth-, or nose-piece the subject rebreathes air from a closed system in which the carbon dioxid produced is absorbed by soda lime, and

as the oxygen is consumed it is replaced by oxygen in known amounts. The air within the apparatus is kept in constant circulation by means of a blower. A small spirometer is inserted in the circuit as an expansion chamber and records volumetrically on a smoked drum the respiratory movements. Knowing the weights of oxygen used and carbon dioxid produced, one can readily calculate the heat production. As pointed out by Carpenter, this apparatus is very satisfactory and, indeed, the best for many purposes, especially when used in conjunction with a calorimeter or with the "cot-chamber calorimeter" described by Benedict and Tompkins. We have found, however, that for clinical work the unit apparatus is rather cumbersome. It requires constant checking to see that it is absolutely air tight, for a leak even of a few cubic centimeters either in the apparatus or in the adjustment of the mask, during a fifteen-minute determination, will appreciably affect the result, because such a leak in this type of apparatus will be equivalent to the loss of so much oxygen and not equivalent to the loss of so much air, as is the case in the gasometer method, thus magnifying the error five times. Furthermore, the accumulative errors of the apparatus fall on the oxygen and not on the carbon dioxid determination, thus causing errors in the calculation of the respiratory quotient and heat production. The absorbing chemicals must be changed frequently, and with the repairing and constant checking of the apparatus it is, on the whole, difficult to use in clinical work, particularly if many determinations are to be made.

(*b*) *Portable Unit Apparatus*.—The portable respiration apparatus recently devised by Benedict[12, 13, 21] for clinical work is a modification of his unit apparatus described above. It is designed primarily to give a rapid and at the same time a comparatively accurate measurement of the oxygen consumption without involving analyses or weighing. We have not adopted this apparatus for

routine work, as we prefer to determine with greater accuracy not only the oxygen consumption but also the carbon dioxid elimination, since the heat production can thereby be more exactly calculated. Moreover, the difficulties inherent in the closed-circuit type of apparatus mentioned above are still present in the portable unit. In addition, in the early models there is the danger of the oxygen-rich mixture catching on fire, which, although it may not injure the patient, is at least disconcerting. The chief objection to the apparatus for clinical work is the fact that it cannot be cleaned and the patient is exposed to the serious danger of infection by rebreathing contaminated air.

(*c*) *Gasometer.*—For clinical work the gasometer method introduced by Tissot in 1904 is considered by us the most satisfactory. Briefly, the determinations are made in the following manner: A mask is tightly adjusted over the patient's mouth and nose and, by means of expiratory and inspiratory valves, the total volume of the patient's expired air is collected in a gasometer for a known period of approximately ten minutes. Duplicate determinations are made of the carbon dioxid and oxygen content of the expired air, the analyses being done in the Haldane gas analysis apparatus. Since the ventilation rate for each minute is known and the percentages of carbon dioxid produced and oxygen absorbed, it is possible to calculate by means of calorie tables the total calories produced each hour.

The gasometer method is particularly suitable for clinical work because each step in the procedure can be checked by a second assistant, reducing to a minimum the chance of technical errors. Unlike in the work with the closed-circuit apparatus, no appreciable error is introduced by failing either to start or to stop the experimental period at exactly the end of a normal respiration, a difficult thing to do with accuracy in the case of patients who breathe irregularly. Furthermore, the air inspired by the patient

is fresh, clean air and not the exhalations of previous patients, as in the closed-circuit type of apparatus. Moreover, all parts of the apparatus that come in contact with the patient or with the air that he breathes can be thoroughly cleaned. Although the method requires care and accuracy in every part of the procedure, it is possible to teach the technic to laboratory workers who have had no preliminary scientific training other than that obtained in high school. The most difficult step in the procedure is the analysis of the expired air. This, however, we have found to be inconsiderable. Our assistants can obtain routinely duplicate analyses agreeing within 0.04 per cent. for carbon dioxid and 0.06 per cent. for oxygen, and they are able also to take entire care of their gas analysis apparatus. The equipment necessary for this method is simple and inexpensive, and if properly constructed is rarely out of order and, except for cleaning, requires very little mechanical care. Furthermore, the apparatus is free from the many mechanical difficulties inevitably inherent in a closed-circuit system in which the air current is driven by an electric pump. In the metabolism laboratory at the Mayo Clinic we have done more than 12,000 tests and are now averaging 32 cases a day, and have developed a very definite and routine procedure which has decreased the probability of a technical error occurring in less than 1 per cent. of the tests.

SECTION II

DETAILS OF TECHNIC

A. THE PATIENT

1. **Postabsorptive Condition.**—Since the time of Lavoisier the influence of food on the metabolic processes has been recognized. In a series of investigations on food ingestion Benedict and Carpenter[16] conclude "that the ingestion of all kinds of food in any amount results in an increment in the metabolism." The mechanical work of chewing and even the drinking of liquids, especially in large amounts, increase the metabolism, although the increases are small. Lusk found that in man the increase in heat production after a large protein meal amounted to 46 per cent. and the effect did not disappear for about twelve hours; with carbohydrate and fat the result was less striking, but a rise of 20 per cent. was not uncommon. Soderstrom, Barr, and Du Bois studied the effect on the metabolism of a small breakfast of bread, coffee, milk, and sugar, totaling 222 cal., and showed that there was an average increase of 7 per cent. in the first hour after such a breakfast, and in the second and third hours, 2 per cent. In other words, the effect was small and of short duration. Benedict, however, rightly insists that the subject should be in the so-called "postabsorptive" state when absorption of material from the alimentary tract has ceased, this being with adults generally twelve hours after the last meal. For this reason we require all our patients to go without breakfast and caution them not to eat heartily the night before the test.

2. **Muscular Activity.**—Much of the earlier work on metabolism was vitiated because the subjects were not quiet during the test.

Benedict and Carpenter[15] have repeatedly emphasized the importance of complete muscular repose, and, in fact, they use a recording device to obtain graphic records of the degree of activity of the subject. For a time we made use of similar graphic records, but have found it more satisfactory to have one of our laboratory assistants with the patient to record any body movements and to evaluate their significance at the time of the observation instead of attempting later to interpret a tracing.

3. **Preliminary Rest Period.**—Benedict and Carpenter[16] advise, furthermore, that there should be a preliminary rest period of at least thirty minutes or preferably longer, so that one may be certain that the basal level has been reached. We require a preliminary rest period of at least twenty minutes before the mask is adjusted. It is obviously desirable when many cases are being studied to make this rest period as short as possible and yet of sufficient length to obtain the basal rate. With this point in view we have studied 44 cases in which the metabolic rate was determined after varying preliminary periods of rest. The data are summarized in Tables 2 and 3. It will be seen that in these 44 cases there is no material difference in the average metabolic rate produced by the prolongation of the preliminary rest period beyond twenty minutes. Sixteen of the patients showed a decrease in the metabolic rate as a result of resting over one-half hour; 7 cases showed no change, and 21 cases showed not a decrease but an increase in the metabolic rate by prolonging the rest period, possibly due to the tendency of certain patients to be annoyed and irritated by the delay. Du Bois also found "a distinct tendency for the patient to become more restless as the observation progresses,"[37] and showed that the metabolism is usually higher in the second hour than in the first.

In another group of 20 cases we determined the metabolic rate directly the patient went to bed, and then made a second determi-

nation after the patient had been resting quietly for at least twenty minutes. The average metabolic rate of these 20 cases determined

TABLE 2. EFFECT ON TOTAL CALORIES PER HOUR AND ON THE METABOLIC RATE OF VARIATIONS IN THE LENGTH OF THE PRELIMINARY REST PERIOD

					A After average rest of 18 minutes			B After average rest of 55 minutes			Diff. A − B	
Case	Sex	Age	Height cm.	Weight kg.	Rest period minutes	Metabolic rate per cent	Total calories per hour	Rest period minutes	Metabolic rate per cent	Total calories per hour	Metabolic rate	Total calories (In per cent of A)
178051	F	40	163.2	47.1	17	+103	108.2	65	+99	106.3	−4	−2
136490	F	46	160.6	55.1	19	+ 51	85.6	49	+58	89.4	+7	+4
188879	F	45	165.1	52.2	19	+ 48	83.3	53	+48	83.1	0	0
258370	F	20	148.6	49.9	17	+ 19	62.2	128	+39	72.6	+20	+17
191547	F	44	160.6	76.2	17	+ 16	74.9	40	+15	74.8	−1	0
248622	F	50	157.5	40.0	20	+ 5	49.0	45	+9	51.4	+4	+5
240206	M	19	175.2	72.3	18	+ 5	80.7	41	+1	77.3	−4	−4
239016	M	22	174.6	73.6	17	+ 1	75.2	38	+3	77.2	+2	+3
43495	M	49	172.1	63.9	19	− 2	66.0	40	−9	61.1	−7	−7
227359	M	31	172.1	43.0	20	− 5	55.4	40	−6	55.1	−1	−1
285194	M	33	193.4	80.0	13	−12	72.6	30	−12	72.7	0	0
214168	F	42	151.1	38.5	20	−13	40.0	45	−14	39.4	−1	−2
43495	M	49	172.1	64.1	18	−17	56.2	51	−26	49.9	−9	−11
135597	F	54	154.3	47.4	17	−17	41.7	40	−17	41.5	0	0
43495	M	49	172.1	64.6	19	−18	55.9	49	−19	54.9	−1	−2
43495	M	49	172.1	64.3	20	−18	55.7	41	−11	60.6	+7	+9
43495	M	49	172.1	64.2	20	−21	53.5	42	−23	52.4	−2	−2
158414	F	49	164.4	79.1	15	−26	49.9	182	−25	49.8	+1	0
262235	F	49	160.6	68.6	19	−27	45.3	45	−29	44.2	−2	−2
57768	F	38	148.6	63.0	20	−29	40.3	42	−29	40.5	0	0
214168	F	42	151.1	39.6	15	−29	33.3	45	−29	33.1	0	0
Average 21 cases					18	+1	61.2	55	+1	61.3	0	0

without any preliminary rest period was +37 per cent., and after an average rest period of twenty-eight minutes +26 per cent.,

showing a marked decrease as a result of the rest period. The complete data are given in Table 4. As a result of the experiments summarized in Tables 2, 3, and 4 we have concluded that twenty

TABLE 3. EFFECT ON TOTAL CALORIES PER HOUR AND ON THE METABOLIC RATE OF VARIATIONS IN THE LENGTH OF THE PRELIMINARY REST PERIOD

					A After average rest of 27 minutes			B After average rest of 57 minutes			Diff. A - B	
Case	Sex	Age	Height cm.	Weight kg.	Rest period minutes	Metabolic rate per cent	Total calories per hour	Rest period minutes	Metabolic rate per cent	Total calories per hour	Metabolic rate	Total calories (In per cent of A)
238402	F	34	172.1	49.9	22	+77	102.1	45	+77	101.9	0	0
258370	F	20	148.6	49.9	26	+46	76.1	134	+56	81.5	+10	+7
258370	F	20	148.6	49.2	28	+41	73.4	128	+44	75.0	+3	+2
247746	M	47	174.6	73.0	23	+13	81.8	43	+9	79.0	-4	-3
281509	F	32	153.1	42.5	27	+13	56.1	44	+15	56.9	+2	+1
262187	F	40	161.6	63.3	29	+11	66.9	55	+28	76.6	+17	+15
81483	F	20	165.7	46.9	24	+7	59.2	45	+4	57.7	-3	-3
273186	F	40	160.7	54.8	22	+1	56.6	40	+1	56.6	0	0
43495	M	49	172.1	64.0	26	-3	65.6	49	+2	69.3	+5	+6
43495	M	49	172.1	64.0	26	-3	65.5	49	+2	69.2	+5	+6
	M	36	165.7	47.7	29	-4	57.1	55	-1	58.9	+3	+3
261342	M	33	177.8	64.0	34	-6	66.7	55	-5	67.6	+1	+1
261342	M	33	177.8	64.0	34	-6	66.7	79	-2	69.8	+4	+5
280182	M	13	119.2	21.0	28	-12	33.9	50	-10	34.9	+2	+3
285194	M	33	193.4	79.7	39	-13	71.6	58	-15	70.5	-2	-2
285194	M	33	193.4	80.4	25	-13	72.3	42	-11	73.8	+2	+2
43495	M	49	172.1	64.2	22	-14	58.3	47	-13	59.1	+1	+1
285194	M	33	193.4	80.2	25	-15	70.8	44	-16	69.8	-1	-1
259013	F	46	155.6	96.1	22	-18	57.9	56	-19	57.1	-1	-1
259013	F	46	155.6	95.6	22	-18	57.6	44	-13	61.2	+5	+6
259013	F	46	155.6	95.4	21	-18	57.5	47	-17	57.8	+1	+1
280576	M	48	176.0	66.2	27	-19	56.6	45	-16	58.6	+3	+4
278793	F	12	149.7	19.5	30	-42	26.0	65	-43	25.5	-1	-2
Average 23 cases					27	0	63.3	57	+ 2	64.7	+2	+2

minutes is a sufficiently long rest for the determination of the basal metabolic rate, provided no strenuous exercise preceded the rest period.

The effect on the basal metabolic rate of prolonged rest in bed

TABLE 4. COMPARISON OF TOTAL CALORIES PER HOUR AND OF METABOLIC RATES DETERMINED WITHOUT A PRELIMINARY REST PERIOD WITH THE TOTAL CALORIES PER HOUR AND THE METABOLIC RATES AFTHR AN AVERAGE PRELIMINARY REST PERIOD OF TWENTY-EIGHT MINUTES.

Case	Sex	Age	Height cm.	Weight kg.	A. Without preliminary rest period		B. With preliminary rest period			Decrease produced by rest in bed	
					Metabolic rate per cent	Total calories	Number of minutes of rest	Metabolic rate per cent	Total calories	Metabolic rate	Total calories (In per cent of A)
233634	F	21	158.7	57.3	+109	122.5	18	+92	112.0	17	9
247539	M	46	168.3	59.3	+ 93	123.9	19	+83	117.8	10	5
288448	M	35	171.6	60.0	+ 92	130.0	32	+71	116.0	21	11
246671	M	45	168.9	52.0	+ 86	114.2	23	+71	104.7	15	8
288345	F	41	157.7	62.0	+ 62	94.8	35	+54	90.5	8	5
288369	F	21	157.8	50.5	+ 57	86.6	42	+52	83.5	5	4
246989	F	32	161.3	49.5	+ 50	82.4	17	+39	76.8	11	7
288480	F	16	173.4	37.3	+ 40	78.2	31	+18	66.0	22	16
241268	F	30	158.1	52.6	+ 28	71.4	16	+19	66.7	9	7
288628	F	30	164.2	55.5	+ 25	72.7	40	+17	68.2	8	6
287708	F	25	162.6	50.8	+ 22	68.8	33	+16	65.5	6	5
247988	M	21	168.3	56.7	+ 17	76.1	23	+12	72.5	5	5
287516	F	33	160.1	71.4	+ 16	73.5	31	+ 1	64.3	15	13
247514	M	22	182.9	59.7	+ 15	80.8	21	+10	77.3	5	4
247241	F	52	162.6	49.1	+ 14	59.9	18	- 1	52.1	15	13
287706	F	36	167.5	56.4	+ 11	66.3	34	+ 2	61.1	9	8
247984	F	40	156.9	46.7	+ 8	55.6	20	- 3	49.9	11	10
279555	F	18	162.2	47.4	+ 6	59.7	29	- 1	55.9	7	6
288447	F	33	173.4	81.1	+ 3	73.3	31	-10	64.2	13	12
107386	F	27	166.3	49.6	- 11	51.0	40	-20	45.5	9	11
Average 20 cases					+ 37	82.1	28	+26	75.5	- 11	- 8

of several days' or even weeks' duration has not been thoroughly investigated. It is not unlikely that even normal persons may have a slightly lower basal metabolic rate after prolonged rest in bed. Such a decrease, if it does occur in normal persons, must be slight, for Boothby has found that the basal metabolic rates of 23 patients who recovered their health after operations and who had been confined in the hospital for between twenty and fifty days, most of the time in bed, were within ± 10 per cent. of the Du Bois normal standard. As Lusk[55] states, this establishes the validity of the use of this measure of the basal metabolism as a criterion of an altered metabolism in hospital patients. We have found, however, that there is an average decrease in the basal metabolic rate of approximately 10 per cent. in patients with hyperthyroidism produced by several days' rest in bed; in some of the cases the drop in the metabolic rate is very marked, while in others it is slight. Such a decrease when it occurs can rightly be interpreted as indicating a decrease in the hyperthyroid intoxication of the patient, and therefore a general improvement in his condition due to the rest in bed.

4. **Effect of Body Temperature.**—The fluctuations in the body temperature that occur from day to day in normal healthy persons,[15] while possibly accompanied by corresponding slight variations within normal limits of the basal metabolic rate, are of no importance clinically. If the temperature is elevated above the normal limits (99° F.), however, the metabolic rate is materially increased. This has been shown in typhoid fever by Coleman and Du Bois, and in malaria by Du Bois and Barr. We have repeatedly and consistently observed an increase in the metabolic rate above an individual's basal level as a result of the development of a cold, sore throat, tonsillitis, or other infection accompanied by a rise in the body temperature. Therefore whenever the significance of the basal metabolic rate is being studied, the presence of a febrile condition must be ruled out by carefully obtaining the body tempera-

ture. For instance, no conclusions as to the degree of primary over- or underactivity of the thyroid gland are justified from the level of the basal metabolic rate unless the temperature at the time of the test is normal.

5. **Character of Respiration.**—In controlling patients we have considered it very important to impress on them, particularly if it is their first test, the necessity of breathing naturally. Patients have a tendency to vary the depth and regularity of their respirations during the test. While this does not affect the total metabolism materially, nevertheless it does alter the respiratory quotient. If there is forced breathing during the test, carbon dioxid is washed out of the body, and since the oxygen absorption is not correspondingly affected, the respiratory quotient, in consequence, will be high. On the other hand, if the patient force breathes shortly before the determination and the mask is adjusted before the carbon dioxid has again accumulated to the normal in the body, then the respiratory quotient will tend to be low (Douglas and Haldane, Boothby[28]). If as a result of this abnormal breathing the resultant respiratory quotient is either below 0.71 or above 1.00, the calculations are carried out as though the quotients were 0.71 and 1.00 respectively. Such abnormal quotients indicate, as a rule, a nervous condition on the part of the patient or an error in technic. It is advisable, therefore, to repeat such cases, although we have rarely found a sufficient change in the check determination to affect the clinical value of the previous test.

6. **Effect of Sleep.**—Benedict and Carpenter[16] consider it important to note any drowsiness or sleep which may occur during the test. "The effect of external muscular activity is to change the total metabolism, while the effect of drowsiness or sleep is to change the apparent character of the respiratory exchange." They[15] also found the metabolism 8 to 10 per cent. higher when the subject was lying awake than when he was sleeping. In clinical work,

however, it rarely happens that a patient falls asleep during the test.

7. **Body Position.**—The question of body position as a factor in the determination of the basal metabolic rate must be considered. Benedict and Joslin state that the metabolism as measured in the chair calorimeter is some 20 to 30 per cent. greater than with the bed calorimeter or with the respiration apparatus. However, as they point out that there was a variable amount of muscular movement in the experiments quoted above, we consider that these results do not necessarily indicate the true effect of body position. Johansson found the carbon dioxid output 6 per cent. higher when the subject was sitting than when lying. Emmes and Riche, using the unit apparatus, found that the oxygen consumption averaged 7.6 per cent. higher with the subject sitting upright in a chair with the head supported than when lying flat in bed. Soderstrom, Meyer, and Du Bois conclude that the metabolism averages 3 per cent. lower with the patient in the semireclining position than when lying at rest. We carried out a short series of experiments to determine the metabolic rate when the patient was sitting at rest in a straight-backed chair and when lying at rest. The patient was allowed to rest quietly in bed, flat on his back, twenty minutes before the first metabolic rate determination was made. At the end of this test the patient was arranged in a fairly comfortable straight-backed chair, with or without head support, and again allowed to rest quietly twenty minutes before the metabolic rate was determined. The data are summarized in Table 5. The average metabolic rate in the 24 cases studied with the patients seated in a chair was +29 per cent., and when lying at rest in bed it was +27 per cent. Thirteen of these cases showed an average increase of 7 points in the metabolic rate when sitting in the chair over the rate determined in bed; 2 cases remained unchanged and 9 showed an average decrease of 5 points. These results demonstrate no con-

sistent variation in the basal metabolic rate due to body position. The slight variations found are probably due to a more complete muscular relaxation with greater comfort in one instance than in the other, with the probabilities of obtaining a lower and, therefore, a truer basal metabolic rate in bed. For this reason we carry out practically all our determinations with the patients in bed, flat on their backs, although we do not hesitate to allow a patient to be in a semireclining position if he is thereby made more comfortable.

8. **Observer's Chart.**—A careful record is kept of each patient while in the laboratory (Form I, Appendix). The time at which the preliminary rest period begins, that is, immediately when the patient is comfortable in bed, is recorded, and during this period several counts of the heart and respiration rates are made. The heart-beat is counted for the full minute by means of a stethoscope at the apex of the heart and the observer notes whether the heart-beat is regular or irregular. The rate and character of the respiration, whether shallow, deep, forced, regular, or irregular, are recorded. The temperature and blood-pressure are taken after the patient has rested quietly in bed for ten minutes. For our blood-pressure readings we use a Tycos apparatus and take the systolic reading at the point at which the sound first comes through and the diastolic reading the third phase, that is, the point at which the sound begins to be "muffled," which is synchronous with a sudden decrease in the amplitude of the swing of the needle.

At the end of the twenty-minute rest period the mask is adjusted with the precautions given on page 35. With the arrangement of our apparatus it is possible for the observer to see when the valve on the gasometer is turned on to the patient or off, so that the exact time to the seconds of starting and ending the test can be noted by the observer. The observer's time should agree within five seconds of the reading on the stop-watch, thus giving a check on gross

TABLE 5. COMPARISON OF TOTAL CALORIES PER HOUR AND OF METABOLIC RATES DETERMINED AFTER REST IN BED WITH THE TOTAL CALORIES PER HOUR AND WITH METABOLIC RATES DETERMINED AFTER CORRESPONDING REST SITTING IN A STRAIGHT BACKED CHAIR WITHOUT HEAD SUPPORT

Case	Sex	Age	Height cm.	Weight kg.	After rest in bed: Length of rest period minutes	After rest in bed: Metabolic rate per cent	After rest in bed: Total calories	After rest in chair: Length of rest period minutes	After rest in chair: Metabolic rate per cent	After rest in chair: Total calories	Difference in metabolic rate (at rest in bed as standard)	Percentage variation of total calories (at rest in bed as standard)
233634	F	21	158.7	57.3	21	+81	103.7	22	+80	103.2	- 1	0
288530	F	22	157.6	66.3	24	+81	112.0	21	+75	107.8	- 6	- 4
247326	F	46	158.7	45.4	21	+66	85.4	30	+71	87.9	+ 5	+ 3
248664	M	41	169.5	49.2	20	+56	93.3	23	+72	102.5	+16	+10
289692	F	38	159.0	46.6	23	+47	77.9	22	+53	81.0	+ 6	+ 4
196577	M	38	177.5	66.2	24	+45	105.0	22	+52	110.0	+ 7	+ 5
248086	F	38	172.7	56.3	16	+39	84.0	18	+37	83.2	- 2	- 1
289409	F	39	170.7	58.8	43	+37	84.0	24	+25	76.7	-12	- 9
249320	F	38	157.5	56.2	22	+35	76.7	32	+38	78.5	+ 3	+ 2
289864	F	56	164.5	55.1	23	+35	75.1	21	+43	79.9	+ 8	+ 6
264592	F	39	168.0	72.0	25	+31	85.8	22	+36	89.5	+ 5	+ 4
195605	F	27	162.6	52.4	11	+28	73.1	17	+24	70.4	- 4	- 4
195605	F	27	162.6	51.8	15	+24	70.5	18	+24	70.6	0	0
289582	F	30	161.6	50.3	21	+24	68.7	21	+24	68.7	0	0
288656	F	43	165.9	52.6	25	+15	65.1	23	+22	68.7	+ 7	+ 6
290261	F	61	161.9	55.5	20	+ 9	58.8	20	+11	59.5	+ 2	+ 1
288709	F	40	159.5	67.2	21	+ 8	66.4	25	+ 2	62.2	- 6	- 6
288438	F	59	155.8	39.2	22	+ 7	49.6	28	+ 6	49.5	- 1	0
173156	F	35	162.1	42.5	33	+ 6	54.4	26	+11	57.2	+ 5	+ 5
289935	F	17	163.0	67.8	24	+ 1	69.7	25	-12	61.2	-13	-12
234034	F	46	158.0	64.2	22	- 2	58.0	21	+ 9	64.9	+11	+12
288548	F	52	165.5	55.2	24	- 3	54.4	21	+ 5	58.5	+ 8	+ 8
280256	F	51	165.0	44.9	25	- 5	48.6	23	- 7	47.7	- 2	- 2
289526	M	60	167.4	55.0	25	- 9	53.7	25	- 2	58.0	+ 7	+ 8
Average 24 cases					23	+27	73.9	23	+29	74.9	+2.5	+2.5

misreading of the latter. When the mask is on, a complete record of the patient's mental and physical condition is kept, as well as of the pulse and respiration rates. Thus the observer notes whether the patient is quiet, records any movements, whether slight or marked, and whether the patient was apparently asleep or nervous and worried. At the end of the test the patient's height (bare feet) in centimeters and weight (without clothing) in kilograms are recorded and checked.

9. **Repetition of Test.**—The necessity for a repetition of the test is dependent on two distinct considerations—the avoidance of technical laboratory mistakes and the elimination of physiologic errors.

Laboratory errors are best detected and avoided by doing two complete determinations each time the patient comes to the laboratory until the laboratory routine has become so perfected that material variations in the results of the duplicate tests do not occur.

Physiologically, however, in an extremely nervous person a basal rate occasionally cannot be obtained the first time the patient comes to the laboratory. In order to rule out the effect of nervousness or temporary slight indisposition the patient is instructed to return the following morning for a second test, instead of repeating the determination on the same day. In such instances the metabolic rate will occasionally be as much as 10 points lower than that obtained at the first test when the patient was unduly nervous and frightened about an unknown procedure, often aggravated by restlessness during the preceding night. A check reading is particularly important in those patients who have, on their preliminary tests, metabolic rates between +10 and +20 per cent. because slight errors in this range have a greater relative significance, and therefore even the slight effect of nervousness must be ruled out.

In conclusion it must be said that it is essential to secure the co-operation of the patients for correct metabolic rates, and one must

impress on them the necessity of lying absolutely quiet by explaining that muscular movement increases the metabolism and so renders their test inaccurate.

B. THE GASOMETER AND ACCESSORY APPARATUS*

1. **Mask.**—Hendry, Carpenter, and Emmes have shown that the oxygen consumption is practically the same regardless of the breathing appliance used. We have found, however, that in clinical work the patients object strenuously to the mouth-piece, and furthermore, that it requires intelligent co-operation on their part to introduce it correctly and to keep it air-tight throughout the observation. Once the mouth-piece is in place there is a tendency to excess saliva, the drooling of which is most disagreeable. A gas mask (Fig. 1) of the type used for mine rescue work is much more satisfactory. The mask is made of rubber fitted over a flexible metal framework, so that it is possible to mold it to the shape of the individual face. The face-piece has a pneumatic rim around its edge, but it is much safer not to inflate it, for the air valve attached to the rim tends to leak, thus altering the pressure of the mask against the face, with the consequent result that it may not be air-tight.

The mask should be fitted to the patient's face and held securely in place by means of tapes tied in various positions across the mask. For convenience twelve tapes are sewed on each side of a narrow towel which is about 6 inches wide and 18 inches long. The towel is placed on the pillow under the patient's head and the various tapes can be used to tie the face-piece securely without disturbing the patient. One pair of tapes is tied over the mask at the nose and another pair around the chin (Fig. 2). Two pairs of tapes are then tied crosswise over the mask, a pair over the nose, and a final pair

* The entire apparatus may be obtained from H. N. Elmer, 1135 Monadnock Building, Chicago, Ill.

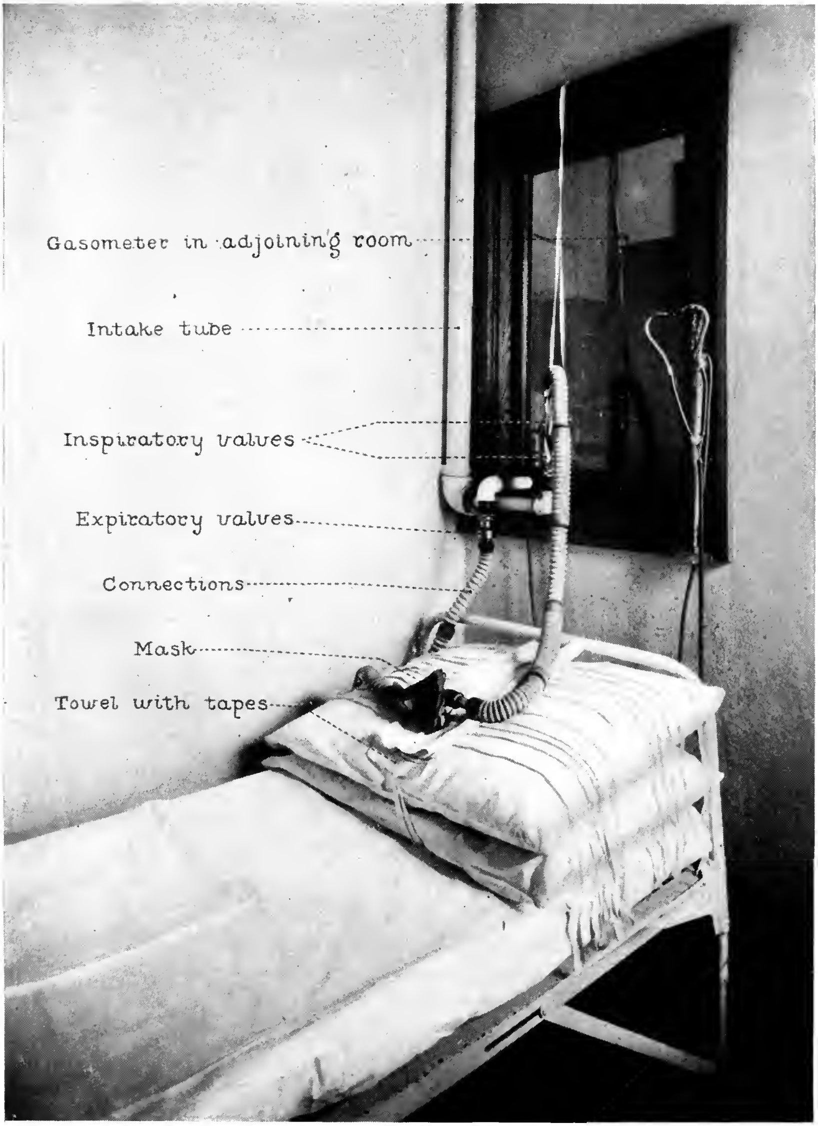

Fig. 1.—Mask and connections showing valves and intake pipe.

around the chin (Fig. 3). The most frequent source of leaks is around the nose and at either of the two corners of the mask, and

extreme care must be taken to avoid them. Smearing the face with vaselin is, however, unnecessary.

The mask and connections are kept clean by washing thoroughly with soap and water and finally by rinsing with bichlorid solution (1 : 1000). The mask itself should be frequently tested

Fig. 2.—Mask with two pairs of tapes adjusted.

for tightness. To do this rubber corks are inserted in the connections and both face-piece and connections are then completely filled with water and allowed to stand one-half hour. It will be found that the mask usually gives way first at the nose.

2. **Valves.**—Carpenter has given an excellent discussion of the various types of air valves and of their relative efficiency. Up to

the present time we have preferred the Douglas valves with mica flaps, although, as Carpenter has shown, they may have an efficiency of only 75 per cent. We overcome this defect by using two of these valves on the inspiratory side at about 2 feet distant from the mask and one valve on the expiratory side (Fig. 1). With this

Fig. 3.—Mask with six pairs of tapes adjusted.

arrangement the loss of any expired air can be completely avoided, because if a slight leak in the valves should occur the expired air would pass back a short distance into the inspiratory tubes, but would not reach the double inspiratory valves; this expired air would be rebreathed on the next inspiration and, therefore, would not be lost. There is very little resistance from these valves to the

passage of air, so that they cause no respiratory discomfort to the patient, and they are, moreover, sufficiently large to take care of any volume of air that a patient breathes, even under conditions of

Fig. 4.—Rubber flutter valve assembled.

extreme muscular exertion. A distinct improvement has been made recently in the Douglas valve by the substitution of a rubber in place of a mica flap.

By far the most efficient air valve is the rubber flutter valve

devised by the British during the war for use on the antigas masks.

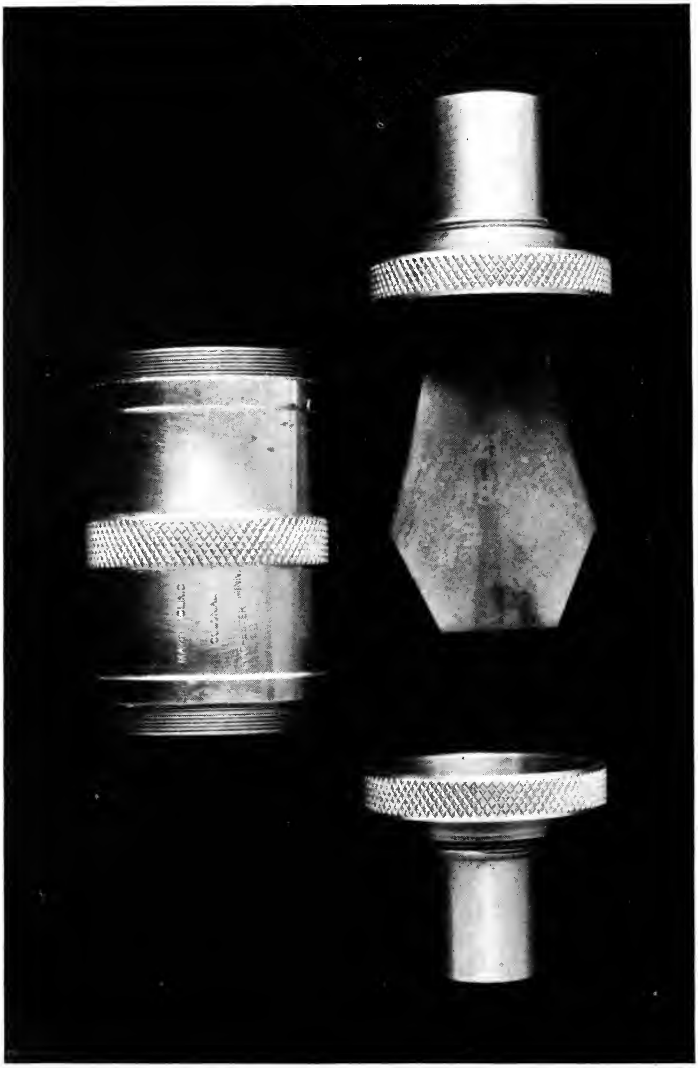

Fig. 5.—Various parts of rubber flutter valve.

The valve offers very slight and negligible resistance to the passage of air and yet is absolutely tight, as proved repeatedly by the fact

that the men were able to stay without any danger in extremely high concentrations of the most deadly gases when the slightest leak would have been fatal. As used on the British and American gas masks the valve opened into the atmosphere. To adapt the valve to our work necessitated the construction of a metal air-tight container suitably designed to insert in the air circuit (Figs. 4 and 5).

3. **Intake Pipe.**—(*a*) *Outdoor Air.*—With the stationary gasometers in the laboratory the two inspiratory valves are mounted on a large intake pipe (Fig. 1) about 2 inches in diameter which leads out of doors so that the subject inspires outdoor air which has a known constant composition: 0.04 per cent. carbon dioxid and 20.93 per cent. oxygen (page 78). The intake pipe can easily be put up in any laboratory and, if possible, should always be used.

(*b*) *Room Air.*—The air in patients' rooms in one of the Rochester Hospitals varied on analysis between 0.04 per cent. carbon dioxid and 20.93 per cent. oxygen to 0.34 per cent. carbon dioxid and 20.70 per cent. oxygen; the average of 100 determinations of the air from different rooms was 0.11 per cent. carbon dioxid and 20.84 per cent. oxygen. In case room air of this average composition is used and no correction made for it in the calculations the resulting metabolic rate will be too high by 3 to 6 points; if there is more than 0.30 per cent. of carbon dioxid with a corresponding decrease in the oxygen content the error in the metabolic rate may be as high as 16 points. On the other hand, analyses of the room air made before and after opening the window wide show that three to five minutes is sufficient to render the composition of the room air within 0.02 per cent. of that of out-door air, a neglect of which will produce no appreciable error in the calculated metabolic rate. With the movable gasometer it is more convenient in routine work to air the room by opening the window wide from three to five

minutes during the preliminary period than to carry an extra long inspiratory tube that will reach out-doors. When using room air the inspiratory tube consists of corrugated tubing, 2 or 3 feet long, with double inspiratory valves; the tubing is hung over the top of the bed so that the valves are upright. It must be remembered that variations in the metabolic rate of 3 or 4 points cannot be considered significant unless either out-door air has been used or control analyses made of the composition of the room air at the site of the opening of the inspiratory tube at the time of the test.

4. **Connections** are made from the valves to the mask by corrugated tubing (Fig. 1) which does not tend to collapse or kink and thus cut off the air supply to the patient. They are made sufficiently long to meet the needed requirements by joining various lengths of the corrugated tubing by brass connections. With the movable gasometer the connections are long enough so that the apparatus during a test may be stationed just outside the patient's room. When using a long connecting tube additional time is necessary to wash out the increased dead space with the expired air (page 51). The tubing must be carefully watched for leaks, because the carbon dioxid of the expired air tends to rot the rubber. To do this the tubes should be filled with water and hung up for ten minutes. A leak in the tubing will allow the water to trickle through on to the dry outer linen covering and so is readily detected.

5. **Gasometer.**—The gasometer method of determining the respiratory exchange was introduced by Tissot in 1904, and has been extensively used in French and in American laboratories. A complete description of the original apparatus and the technic used in Chauveau's laboratory is given by Carpenter.

Although the fundamental principles of the Tissot spirometer have not been changed, a few alterations in detail render the form of apparatus used by us more convenient for clinical use. Figures 6, 7, and 9 illustrate the design of our apparatus as perfected by

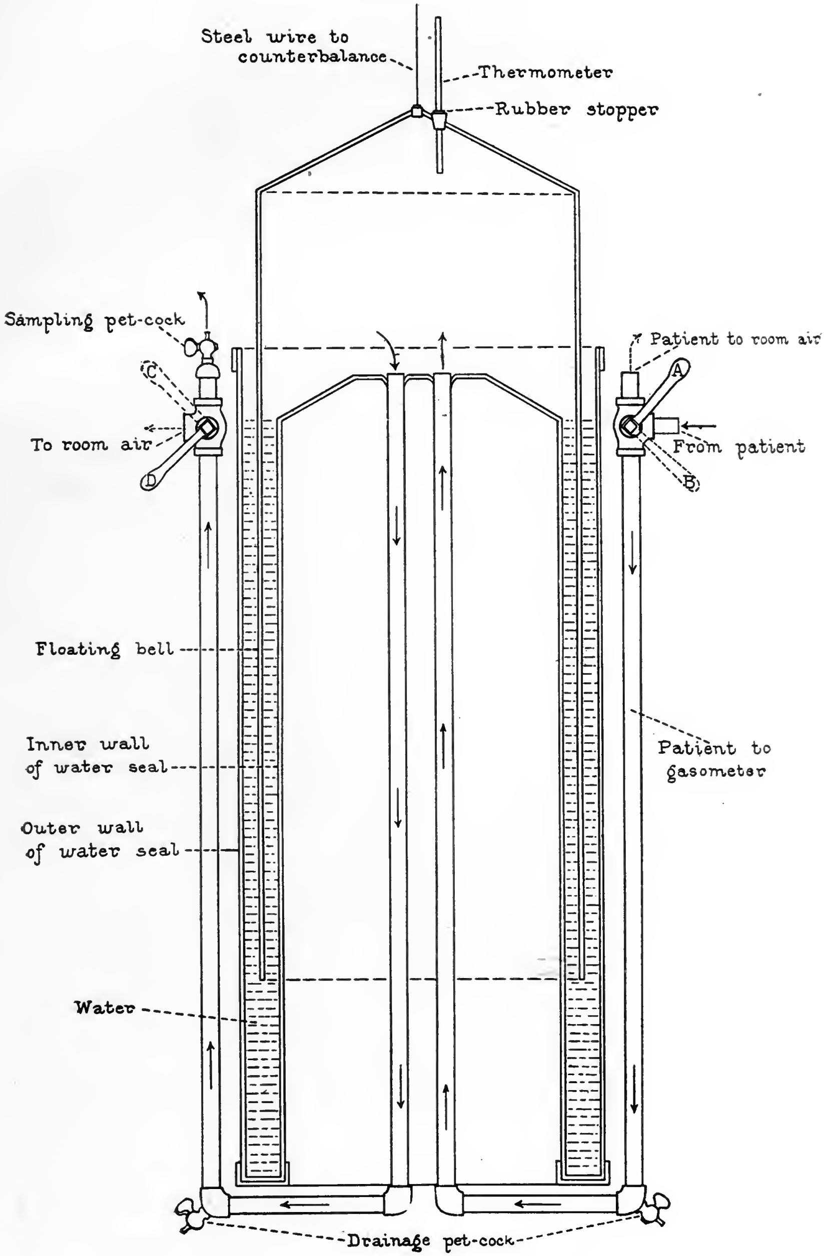

Fig. .6—Cross-section of gasometer .

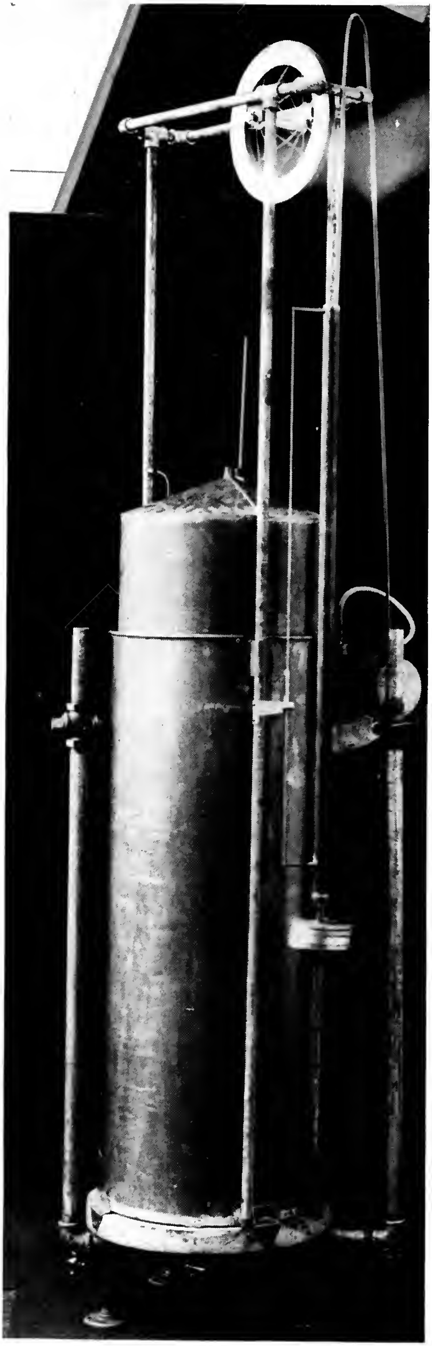

Fig. 7.—Stationary gasometer.

Mr. George Little of the clinic instrument shop. The gasometers

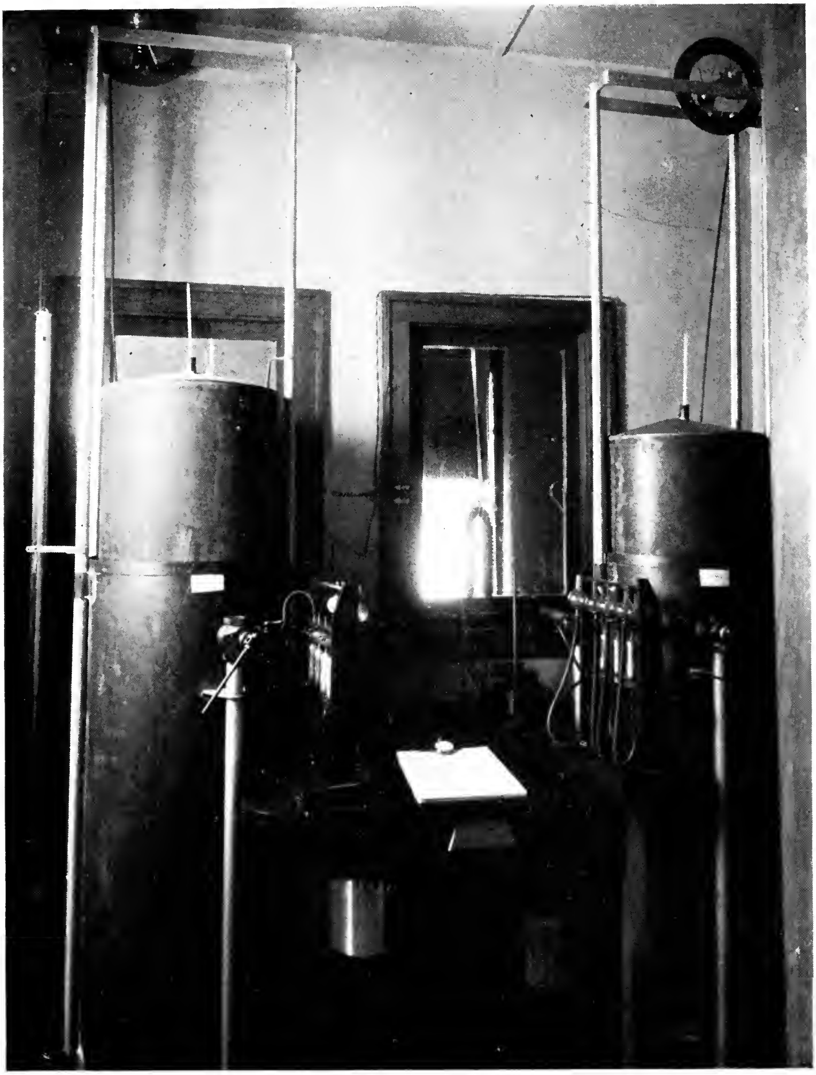

Fig. 8.—Gasometer room.

in the laboratory are stationary and, in addition, we have a gasometer mounted on wheels and of slightly smaller capacity (Fig. 9).

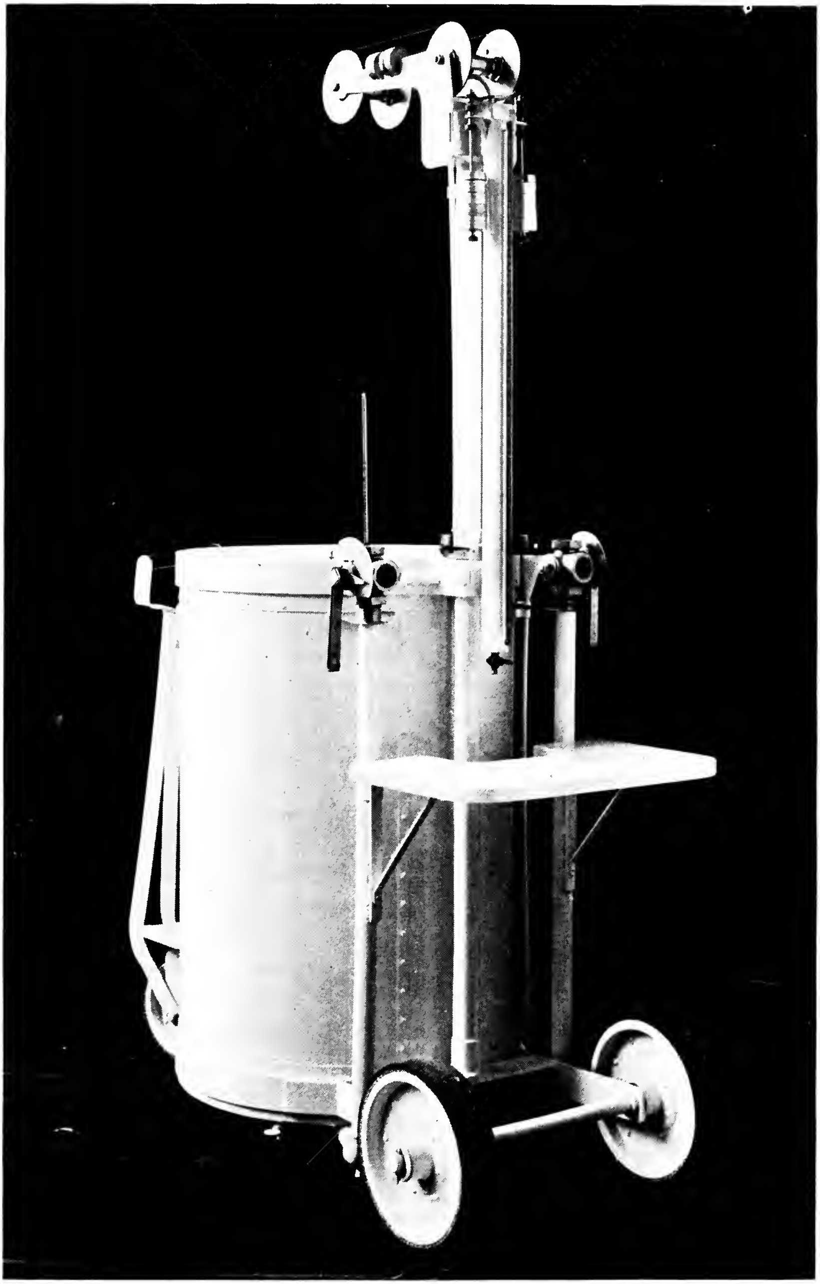

Fig. 9.—Movable gasometer.

With this movable apparatus it is possible to test the patients in their rooms, which is of considerable advantage.

The gasometer (Figs. 6, 7, 9) consists of a thin copper bell, of approximately 125 liters capacity, suspended in a water-bath between double walls of a hollow cylinder which is closed at the top, except for the inlet and outlet tubes. The counterpoise of the bell is hung over ball-bearing wheels by means of steel piano wire. The main weight of the bell is balanced by a long, hollow brass tube (counterpoise tube) on the lower end of which are placed the necessary lead weights to counterbalance the bell exactly. To compensate for the increase in weight of the gasometer bell as it rises out of the water seal a quantity of water equal to the increase in the weight of the bell siphons from a small reservoir into the hollow counterpoise tube. When the lead weights are on the counterpoise tube the bell is in perfect equilibrium at any point in its course, so that when the valve *C* (Fig. 6) is opened to room air the bell will not change its position. One of the lead weights (the balancing weight) is removable, and when it is not on the counterpoise tube the bell will gradually drop if the valve *C* is opened to room air. Whenever readings are taken of the volume of the gasometer this weight must be on the counterpoise tube. For the purpose of sampling, however, the weight is removed and the bell allowed to drop by opening valve *C* until about half the volume of air collected has escaped, thus washing the sampling connections with the expired air. An extra weight (the negative pressure weight) of approximately 300 gm. is placed on the counterpoise tube after the preliminary readings are taken and just before the test is started. This causes a slight negative pressure between the gasometer and the patient and so overcomes the resistance of the air passing through tubes.

The position of the bell is determined by means of two fixed steel pointers reading against a steel tape attached to the counter-

poise tube. The object of the two pointers is to give two readings of the position of the bell, both at the start and at the end of the test, thus giving an excellent check on the readings of the difference in the position of the bell at the beginning and at the end of the experiment. The use of the steel tape attached to the counterpoise tube for reading is preferable to a fixed scale with a movable pointer attached to the bell itself (as is the arrangement on the Tissot spirometer), for a slight swing or tip of the bell might make a distinct change in the level of the pointer, and consequently result in incorrect reading of the volume of air.

To obtain the temperature of the air in the bell a thermometer is inserted through a rubber stopper in the top of the float. The thermometer projects about 4 inches inside the bell, and it is so placed that when the bell is completely down resting on the top of the inner copper cylinder the thermometer fits into the air inlet tube. The thermometer is graduated to one-fifth of a degree Centigrade.

Separate outlet and inlet tubes are arranged on the gasometer as indicated in Fig. 6. The valves are arranged as follows: On the inlet tube leading from the patient to the gasometer there is a three-way valve which when set in position *B* closes the gasometer and allows the expired air from the patient to escape into the room; when set in position *A* the former opening is closed and the expired air passes into the gasometer. When the three-way valve on the outlet tube is put in position *C* the gasometer is open to room air; when in position *D*, the gasometer will be closed if the sampling pet-cock is closed; the latter is open only while taking a sample of air. On the portable apparatus a two-way valve is used at *C* and the sampling pet-cock is inserted directly into the outlet tube below the valve.

The water seal is kept at the level indicated in Fig. 6. It never covers the incline of the inner cylinder, consequently the expired

air is not exposed to a large surface of water, since there might be an appreciable loss of carbon dioxid by water absorption. The level of the water seal drops as the bell rises; this introduces a very small and negligible error in the readings. The water in the tank need be changed only occasionally, for the copper salts from the walls of the gasometer prevent bacterial growth.

To test the bell for tightness the outlet and inlet valves are closed with the bell counterpoised. The bell is put under a fairly heavy positive pressure by placing a weight of 2 kg. on the top of it. Readings are then taken of the gasometer volume and its temperature, also the barometer reading. At the end of half an hour, if no changes have occurred either in the temperature or in the barometer, the gasometer volume should be unchanged. We are careful to test our gasometers frequently, and have found that whenever leaks occurred they could always be traced to faulty greasing of the outlet or inlet valves.

6. **Barometer.**—In all volumetric work with gases it is necessary to reduce the observed volume of the gas from the experimental temperature and pressure to the standard temperature 0° C. and the standard barometric pressure of 760 mm. dry. A good barometer,* such as supplied to the United States Weather Bureau for ordinary observatory work, is necessary. This barometer should have a metric scale with a vernier reading to tenths of a millimeter, and a thermometer graduated in degrees Centigrade.

7. **Calibration of Gasometer.**—The gasometer readings are made on a steel tape, fixed on the counterpoise tube. The tape is graduated to 0.10 cm. and is read by means of stationary markers to 0.05 cm. It is, therefore, necessary to determine the factor of the gasometer in order to convert the linear rise of the bell into a unit of volume. This factor is derived in the following manner: The

*A suitable barometer may be obtained from Henry J. Green Co., 1911 Bedford Avenue, Brooklyn. N. Y., Catalogue: No. 1.

bell of the gasometer is a cylinder, and the circumference of it is determined by measurement at several points from top to bottom, either with the bell in position or removed entirely from the gasometer. On our gasometer *A* the following measurements of the circumference were taken with the bell in position:

Reading on tape, cm.	Circumference of bell, cm.
97	126.0
87	126.0
72	125.9
59	125.9
45	125.8
33	125.8
17	125.8
9	125.8
Average	125.9

Since the radius of a circle $= \frac{1}{2\pi} \times$ the circumference, then the radius to the outside of the wall of the bell $= \frac{1}{2 \times 3.1416} \times 125.9$ $= 20.038$ cm. The radius to the inside of the bell is, therefore, equal to 20.038 cm. minus the thickness of the copper wall as determined by calipers. This radius of the inside of the bell is, therefore, 20.038 cm. − 0.046 cm. = 19.992 cm. Since the area of a circle equals πR^2, then 3.1416×19.992^2 cm. = 1256 sq. cm. Therefore, the capacity of the bell corresponding to a rise of 1 cm. measured by the tape will be equal to 1 cm. × 1256 sq. cm. = 1256 c.c. or 1.256 l., the factor of the gasometer. We read the centimeter scale to the nearest half-millimeter corresponding to a change in volume of 63 c.c.

8. **Collection of Expired Air in Gasometer.**—The gasometer bell is dropped to the bottom of the tank by removing the balancing weight and opening valve *C*, thus forcing out all the air save what is left in the dead space at the top of the tank and in the connecting pipes. When the patient has rested sufficiently to start the test, the mask is tied on with one pair of tapes around the upper part of

the mask and a second pair over the chin. One of the assistants then turns the gasometer inlet valve so that the expired air passes into the tank. While the remaining four tapes are being tied the patient is filling the gasometer and the connections with his expired air. When the gasometer bell has risen to 6 cm. on the tape the valve *C* (Fig. 6) is opened and the bell dropped to the bottom without turning the patient off from the machine. Valve *C* is then closed and the gasometer filled with expired air to a volume corresponding to 3 cm. on the tape. Valve *B* is then turned so that the patient breathes into room air. Valve *C* is opened and the gasometer allowed to drop to about 1.50 on the tape, so that a small air cushion of the patient's expired air is left at the top of the inner tank. The bell should not be lowered so far that it rests on the inner copper cylinder, as its equilibrium is thereby disturbed. The balancing weight is replaced on the counterpoise tube. The position of the bell at the start of the test is taken by reading the level of the two pointers on the steel tape. These readings are recorded to the nearest 0.05 cm., and then the negative pressure weight is added to the counterpoise tube. The inlet valve is quickly turned, so that the patient is once more breathing into the gasometer, and at the same instant the stop-watch is started and the time independently recorded by the observer sitting with the patient. At the end of approximately ten minutes the inlet valve is turned off from the patient, the stop-watch stopped, and the time recorded by the observer. While the mask is removed by the observer, the other assistant removes the negative pressure weight from the counterpoise tube, makes the two final readings on the tape to the nearest 0.05 cm., records the temperature of the gasometer to the nearest half-degree Centigrade, and finally the barometer to the nearest millimeter. All the readings mentioned are checked by the observer. If the differences in the two sets of readings of the position of the bell at the beginning and at the end

of the experiment do not agree, the test is repeated. Likewise, if the duration of the test noted by the observer using an ordinary Ingersoll watch does not agree within five seconds of the time on the stop-watch, the test is repeated. The object of the additional time determination by the observer is to prevent gross misreadings of the stop-watch. The balancing weight on the counterpoise tube is then taken off and the outlet valve *C* and sampling pet-cock opened to room air to wash the connections with the expired air. The gasometer is allowed to drop about one-half its volume, the outlet valve *C* is closed, thus shunting the air current through the open sampling pet-cock and so allowing it to be thoroughly washed (Fig. 8). At the end of one minute the four sampling tubes are filled with the expired air.

9. **Sampling Tubes.**—The sampling tubes (Figs. 8, 11) are those described by Krogh and Lindhard. They have a volume of 30 or 35 c.c. with a two-way tap and small bored tip about 4 cm. long above the tap for the purpose of making connections with the gasometer in sampling. A piece of rubber tubing about 15 inches long connects the sampling tube to its mercury reservoir of about 40 c.c. capacity. The sampling tubes are mounted in fours on a rack, and four samples of expired air are always taken for each test; two are analyzed, and this leaves two extra samples in case of accident. The sampling tubes are filled to the tip with mercury. In sampling, connection is made to the pet-cock on the gasometer by means of heavy walled 3-mm. bore rubber tubing. The tubing is tightly adjusted to the tip of the sampling tube, the mercury reservoir lowered, and the tap on the sampling tube opened. The sampling tube is washed twice with the expired air and the sample collected after the second rinsing. The tap is closed and the mercury reservoir hung up to keep the sample under positive pressure. The tap must be well greased and for this purpose we use a "black rubber" grease, the formula for which is given on page 81. When the sampling tubes

become dirty they are cleaned with concentrated nitric acid, rinsed with distilled water, and thoroughly dried. This is sufficient for the purpose, although it will be found that the "etching" that eventually develops on the inside of the tubes cannot be removed.

10. **Stratification of Air in Gasometer.**—On account of the well-known tendency of air to stratify and, therefore, not form a uniform mixture throughout, doubt has often been expressed as to the possible variation of the percentages of carbon dioxid and oxygen at different levels in the gasometer. Carpenter reviewed the existing evidence on this point and, in addition, published a few new experiments. He concluded that the "uniformity in the composition of the air throughout the spirometer depends on the character of the respiration. . . . When the respiration was quiet and uniform the good agreement of the results indicates that the composition of the expired air was uniform in all parts of the spirometer."

As the accuracy of the gasometer method depends fundamentally on obtaining samples of expired air from the gasometer that represent at least with a negligible error the mean composition of the expired air, we have investigated the question of stratification in considerable detail. The method of procedure was as follows: Samples were taken from the gasometer according to the usual routine described on page 50, with the exception that in addition to the regular sample taken from the middle of the gasometer two additional samples were taken, the one after the bell had been allowed to drop 10 cm. from the top, and the other after the bell had been dropped to within 10 cm. of the bottom. This gave three sets of samples of air collected first from the lower segment of the gasometer, second from the middle segment, and third from the top segment. Analyses were made in duplicate according to our usual custom. Forty-nine experiments were done, in 14 of which no note was made of the length of time elapsing between the collec-

TABLE 6. STRATIFICATION OF AIR IN GASOMETER

Number of Experiments	Method of collection	Air in lower strata		Air in middle strata (regular sample used in calculation of B.M.R.		Air in upper strata		Difference between extremes		Difference of middle strata from average of all three strata		No. of experiments with twice the average differences	
		Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2
14	Without reference to time of collection of expired air.	3.47	16.50	3.51	16.49	3.48	16.49	7	9	3	4	1	1
10	Samples taken directly after the expired air was collected	3.21	16.96	3.23	16.97	3.22	16.96	7	12	3	6	1	0
11	Samples taken after expired air had stood five minutes	3.44	16.77	3.43	16.75	3.43	16.77	6	9	3	3	2	1
14	Samples taken after expired air had stood ten minutes	3.50	16.68	3.50	16.65	3.49	16.66	6	8	2	2	1	2
Average 49 determinations		3.42	16.71	3.43	16.69	3.42	16.70	6	9	3	4	5	5

tion of the expired air and the sampling; in 10, samples were taken as soon as possible after the collection of the expired air; in 11, they were taken after a lapse of five minutes, and in 14, after a lapse of ten minutes.

A study of the experiments summarized in Table 6 shows that the expired air collected in a gasometer has a tendency to stratify. However, if the samples used for calculating the metabolic rate are taken from the middle of the gasometer, the error caused by such stratification is negligible, especially if a few minutes are allowed to elapse between the collection of the expired air and the taking of the samples in order that the gas mixture may become more uniform by diffusion. Furthermore, the cases given in Table 6 were taken indiscriminately and, therefore, represent with reasonable probability the usual variations in the type of respiration that one naturally meets in the course of routine work. We conclude, therefore, that the accidental error that might be introduced by the slight stratification that exists in the expired air collected in a gasometer does not invalidate the calculation of the metabolic rate, since such changes that are thereby produced fall within the total experimental error of the method.

11. **Effect on the Carbon Dioxid and Oxygen Content of the Expired Air from Standing in the Gasometer.**—It was likewise important to know whether or not variations in the carbon dioxid and oxygen content of expired air collected in a gasometer changed after prolonged standing, as theoretically it might be thought that the water seal of the gasometer might either take up or give off carbon dioxid. Therefore, we carried out 22 experiments in which three hours elapsed between the collection of the first and second samples. A second set of 16 experiments was done in which the samples were collected the next morning, about twenty hours after the collection of the first sample. All of the analyses were done in duplicate, according to our usual routine. The results are summarized in

TABLE 7. EFFECT ON THE CO_2 AND O_2 CONTENT OF EXPIRED AIR FROM STANDING IN GASOMETER

Number of experiments	Directly after collection of expired air		Three hours after collection of expired air		Twenty hours after collection of expired air		Average of differences regardless of sign		Number of experiments with twice the average	
	Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2	Avg. CO_2	Avg. O_2	CO_2	O_2
22	3.30	16.85	3.31	16.85			3	3	2	1
16	3.49	16.58			3.45	16.63	8	6	2	3

Table 7, and show but a negligible change in the percentages of carbon dioxid and oxygen from standing twenty hours in this type of gasometer.

C. THE HALDANE GAS ANALYSIS APPARATUS

1. **Description of Haldane Apparatus.**—The analyses are done in a portable Haldane gas analysis apparatus (Figs. 10, 11, 12), described very fully by Haldane in his book on Air Analysis. Briefly, a sample of air is taken into the buret and its volume measured; the air is passed back and forth into the tube containing potash solution to absorb the carbon dioxid and then a second reading of the volume made. The contraction in volume of the sample, due to absorption of carbon dioxid by the potash solution, divided by the original volume of the sample, is the percentage of carbon dioxid present in the dry sample of air. In like manner the percentage of oxygen is determined by absorbing the oxygen in potassium pyrogallate solution and measuring the contraction in the volume of the air sample.

The general arrangement of the apparatus is shown in Figs. 11, 12. It consists of a calibrated buret (2) of 10 c.c. volume, a control tube (3) of approximately the same volume as the buret, both surrounded by a water-bath (1), and two absorption pipets of about 30 c.c. capacity, the one containing potash (16) for carbon dioxid

absorption and the other potassium pyrogallate (21) for oxygen absorption. In addition, there are three three-way taps to connect

Fig. 10.—Section of analysis room.

the various parts of the apparatus. One tap (14) connects the buret with either the potash (16) or the pyro absorption pipet (21). An-

other tap (18) is used to connect the control tube with the potash manometer tube (25) or with room air. The third tap (19) is placed

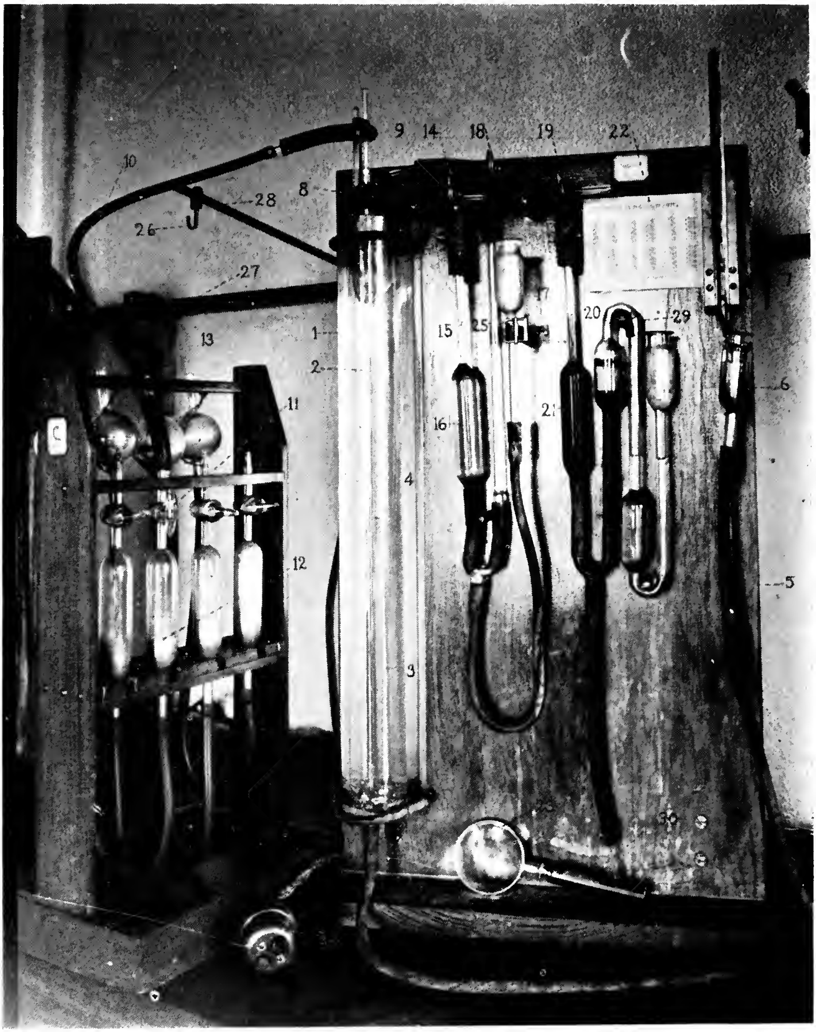

Fig. 11.—Detail of Haldane apparatus.

above the pyro absorption pipet and, while not necessary, is convenient when cleaning the apparatus. On all the three-way taps a

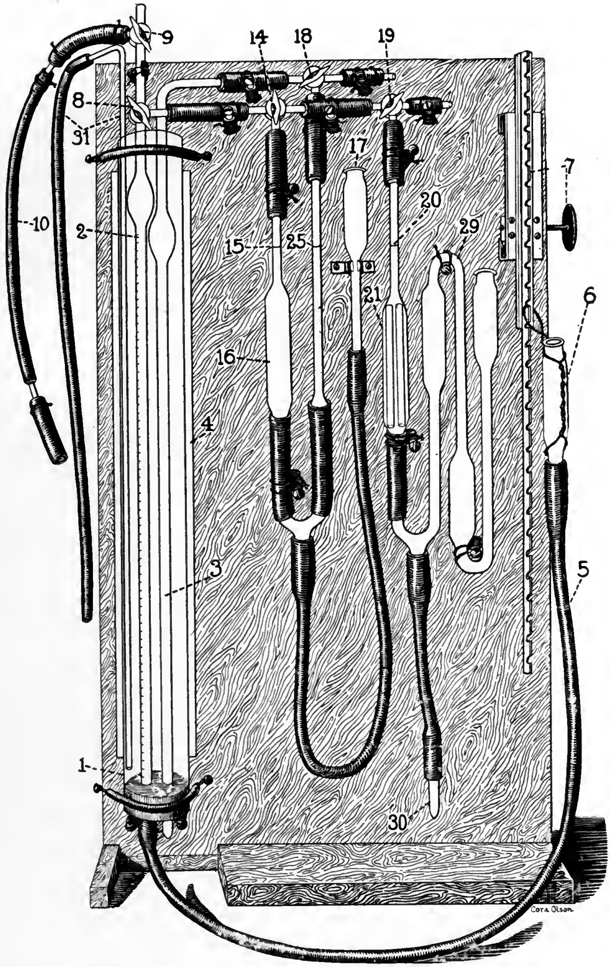

Fig. 12.—1. Water-bath. 2. Buret. 3. Control tube. 4. Glazed glass in back of water-bath. 5. Pressure tubing connecting buret and its mercury reservoir. 6. Mercury reservoir. 7. Ratchet and pinion. 8. Buret tap. 9. Sampling tap. 10. Sampling connection. 11. Two-way tap on sampling tube. 12. Sampling tube. 13. Sampling tube reservoir. 14. Potash tap. 15. Level marking on potash pipet. 16. Potash pipet. 17. Potash reservoir. 18. Control tube tap. 19. Pyro tap. 20. Level marking on pyro pipet. 21. Pyro pipet. 22. Buret corrections. 23. Magnifying lens. 24. Switch for electric light back of Haldane board. 25. Level marking on manometer tube. 26. Hook upon which to hang mercury reservoir for shaking. 27. Shafting going around room to raise and lower 28. 28. Arm from shafting. 29. Seal tube. 30. Solid glass rod for closing pyro filling connection. 31. Tube for compressed air to stir water-bath.

drop of sealing-wax is put on the handle to indicate the position of the short arm. All of the taps must be air-tight, fitting the bore perfectly, so that they turn without binding or making striations. Finally, there are the potash (17) and mercury (6) reservoirs and beyond the pyro tube a seal tube (29) partly filled with dilute potash solution to prevent the pyro from coming in contact with room air. The various parts of the Haldane are shipped dismounted and the buret has an extra tap fused on it to facilitate the calibration.

2. **Calibration of the Haldane Buret.**—To obtain accuracy in gas analysis it is necessary to calibrate the buret carefully because the glass maker may neglect to take into consideration the volume of the openings in the tap; assume that the buret has an absolutely even bore; carry out the calibration with the buret upside down, or he may make some other gross error. In calibrating, the buret is filled with mercury and the weights of the mercury corresponding to various volumetric readings on the buret are determined. Since the volume (V) of a liquid is equal to its weight (W) divided by its density (D) the corresponding volumes of the various weights of mercury are determined. The volume of the mercury thus calculated is compared with the corresponding volumetric readings on the buret and the correction determined.

The buret is first thoroughly cleaned with warm cleaning solution, then rinsed with distilled water, and completely dried by sucking clean air through it. The clean, dry buret is filled through the calibration tap with mercury up to and just within the buret tap. A convenient way of doing this is by suction or by attaching rubber tubing with a mercury reservoir to the lower end of the buret. It is important that no air bubbles are caught by the mercury. When the mercury completely fills the buret and is just within the buret tap the calibration tap is closed and the buret tap is quickly turned, cutting off the head of the mercury column and

immediately withdrawn from its bore, care being taken not to leave behind in the bore any of the minute particles of mercury from the tap. In this way the buret is accurately filled with mercury. The calibration and buret taps must never be left closed with the buret filled with mercury because the expansion of the mercury with the rise of room temperature will burst the buret. The mercury is run slowly down, approximately to the reading 7.0 cm., and is collected in a dry and clean, weighed dish. After gently tapping the buret with a pencil, the accurate reading of the volume of mercury in the buret to 0.001 c.c. is recorded and the total weight to the nearest 0.001 gm. of the mercury and dish found. Care should be taken that no particles of mercury cling to the inside of the buret as the mercury runs out. This usually means that the buret is greasy and should be recleaned. The surface of the mercury in the weighing dish should be brought into contact with the surface of the mercury at the end of the calibration tap, so that a constant amount of mercury is left in the end of the buret after each portion of mercury is collected. The weighing should be done on a fine chemical balance and recorded to the nearest 0.001 gm.

Before weighing the mercury the reading of the buret should be recorded to the nearest 0.001 c.c. The reading of the buret is difficult; it requires great care and may be affected by numerous factors. It seems worth while to enumerate them in detail. To obtain correct readings the buret must be set up during the calibration so that it is perpendicular. A thermometer should be hung near the buret and the temperature noted from time to time. Variations in the temperature affect the buret readings, a fluctuation of one degree causing a change in a volume of 7 c.c. of mercury of approximately 0.001 c.c. The room in which the calibration is being carried out should, therefore, be kept at as constant a temperature as possible and drafts avoided. Likewise care must be taken not to breathe on the buret or to touch it with the hands dur-

ing the calibration. The buret should be gently tapped with a pencil before the reading is taken to obtain a true meniscus of the mercury. The reading lens should be held parallel with the buret with the center of the lens opposite the mercury meniscus. The eyes must be on the correct level before making a reading of the mercury meniscus. To do this the reflections on the mercury of the two 0.01 c.c. markings on the buret just below the mercury meniscus are located and the eyes are on the correct level when these two lines and their reflections exactly coincide.

The weights of successive portions of the mercury are found for various readings of the buret—approximately at 7.0 c.c., 7.3 c.c., 7.5 c.c., 8.0 c.c., 8.5 c.c., 9.0 c.c., 9.2 c.c., 9.4 c.c., 9.6 c.c., and at 9.99 c.c. The calibration is then repeated, without cleaning the buret, determining the weights of mercury at the readings, 7.0 c.c., 7.5 c.c., 8.0 c.c., 9.0 c.c., 9.5 c.c., and 9.99 c.c. It is preferable to do the two calibrations at one sitting and the corrections should check within ±0.001 c.c.

We do not determine the volume of the tap by mercury because it is practically impossible to fill the arms completely with mercury. It is much more accurate to measure the lengths and diameters of the arms of the tap by using calipers and to calculate the volume. The openings in the tap are in the form of a T. On our buret K the length of the longer arm is 8.4 mm. and of the short arm 4.3 mm., and the diameter of both arms is 2.5 mm. Since the volume of the tap equals the length of the arms multiplied by πR^2, then $(8.4 \text{ mm.} + 4.3 \text{ mm.}) \times \left(\frac{2.5}{2}\right)^2 \times 3.1416 = 62.0$ cu. mm. $=$ 0.062 c.c., which is the volume of the tap.

Instead of using the absolute density of the mercury corresponding to the temperature recorded by the thermometer near the buret, we calculate the comparative density of the mercury from the experimental data. In calibrating buret K at the reading 9.999 c.c. the weight of the mercury was 135.127 gm., its density is, there-

fore, $\frac{135.127 \text{ gm.}}{9.999 \text{ c.c.}} = 13.514$. Converting the volume of the tap into the corresponding weight of mercury, 0.062 c.c. × 13.514 = 0.843 gm. Therefore, the total weight of the mercury in the stem and in the buret tap (had the tap been in place and filled with mercury) at the reading 9.999 c.c. would be equal to 135.127 gm. + 0.843 gm. = 135.970 gm., and the final density of mercury as determined experimentally would therefore be 135.970 gm. ÷ 9.999 c.c. = 13.598.

The calculated weight of mercury in the tap added to the weight of mercury corresponding to the volume of the buret at 7.003 c.c. equals 95.259 gm. + 0.843 gm. = 96.102 gm. The true volume of the mercury corresponding to the buret volume of 7.003 c.c. is 96.102 gm. ÷ 13.598 = 7.067 c.c. That is, the buret at this point has an actual volume larger than the volume read by 7.067 c.c. — 7.003 c.c. = 0.064 c.c. The correction at the reading 7.003 c.c. on the buret is, therefore, +0.064. In Table 8 is given the calibration of four points on buret *K*.

When the corrections for the various readings are determined as above they are plotted on millimeter paper and the corrections for each 0.1 c.c. reading of the buret are read off from the curve and listed for use. As stated above, duplicate calibrations are done and care is taken in both determinations to obtain the weight of mercury at practically the same final reading, 9.99 c.c., in order to obtain agreement in the calculated density of the mercury. This method gives a zero correction at the reading 9.99 c.c., thus adopting this value as the "unit" of the buret; it is unnecessary in this type of apparatus to calibrate the buret in terms of a standard cubic centimeter as the unit. Consequently, in case any or all of the corrections are found to be minus it is desirable to recalculate the calibration, deliberately selecting a density of mercury that will give a zero correction for the largest negative correction found by the first calculation; if this is done all the other corrections will be plus, which is a great advantage when calculating the results.

Haldane carries out the calibration with the sides of the buret moistened with water just as it is actually used. The viaration in

Table 8. Calibration Buret No. K.

Volume of Tap
Length of long arm 8.4 mm.
Length of short arm 4.3 mm.
Diameter of arms 2.5 mm.

$$\text{Volume} = (8.4 + 4.3) \times \left(\frac{2.5}{2}\right)^2 \times 3.1416$$
$$= 12.7 \times (1.25)^2 \times 3.1416$$
$$= 0.062 \text{ cc}$$

Log 12.7 10380
" $(1.25)^2$ 19382
" 3.1416 49715
79477

Temp. °C.	Buret reading	Weight of mercury in stem	Weight of mercury in stem and tap	Volume of mercury in stem and tap	Buret correction
23.6	7.003	Wt. container + Hg 102.142 " " 6.883 " Hg in stem 95.259	Wt. Hg in stem 95.259 Wt. Hg in tap 0.843 Wt. Hg in stem & tap 96.102	Log 96.102 98273 " D. of Hg 13348 " Vol. Hg 84925 Vol. Hg = 7.067	Vol. Hg 7.067 Buret reading 7.003 Corr. + .064
23.4	7.501	108.807 6.883 101.924	101.924 0.843 102.767	01186 13348 87838 = 7.558	+ .057
23.6	9.255	132.229 6.883 125.346	125.346 0.843 126.189	10103 13348 96755 = 9.280	+ .025
23.6	9.999	142.010 6.883 135.127	135.127 0.843 135.970	13344 13348 99996 = 9.999	0

Calculation of density of mercury and weight of mercury in tap.

Log 135.127	13076	Log Vol. tap	79477	Wt. Hg at 9.999	135.127	Log 135.970	13344
" 9.999	99996	" D. Hg in stem	13080	" " in tap	0.843	" 9.999	99996
" D. Hg in stem	13080	" Wt. Hg in tap	92557	" " in stem & tap	135.970	" D. of Hg	13348
		Wt. Hg in tap	0.843				

the moisture makes it somewhat difficult to obtain check calibrations, and so we prefer to calibrate the buret dry. The calibration

tap must be fused to the buret and not attached by rubber tubing, because changes in level of the mercury from the top to the bottom of the buret will produce variations in pressure against the rubber tubing, and consequently the latter will not always have the same bore, and an appreciable error in the calibration results. As has been suggested by Haldane, it is possible to calibrate the gas analysis apparatus by determining the percentage error found on analyzing pure outdoor air which has a constant composition of carbon dioxid and oxygen. This method is only applicable if the buret has an absolutely even bore throughout its entire length, and we have found this frequently not to be the case.

3. **Assembling the Haldane.**—The mounting of the various parts of the Haldane is not difficult. If the duplicate calibrations agree the calibration tap is cut off and the end of the buret carefully fire-polished. To clearly define the graduations of the buret, the stem is cautiously warmed over a low flame and a blue skin pencil rubbed hard over the surface of the buret to fill in the figures and markings with the blue lead; the excess is wiped off with a soft cloth. The length of the water-bath (1) is cut so that it will reach from just below the buret tap (8) to about 5 cm. below the 10 c.c. mark on the buret. The control tube should fit in the water-bath with its bulb 1 cm. below the bulb of the buret. A right-angle bend is made in the control tube about 2.5 cm. above the buret tap (8). The end of the control tube is sealed at a point projecting 2 cm. below the water-bath and it is then filled about half-way up its stem with distilled water. By means of a sharp cork borer, moistened with soap solution, two holes are bored in a rubber stopper which should not be more than 1.5 cm. thick. The stopper is fitted into one end of the water-bath and the control tube and buret are put inside the water-bath and through the stopper. The rubber tubing (5), after being thoroughly cleaned of talc and moistened with water, is slipped on the buret. The water-bath, with the buret and control tube in

position, is placed on the Haldane board in front of the glazed glass (4) and is supported by two long screws. It is securely held in place by wires, covered with rubber tubing, across the top and bottom of the water-bath. One by one the taps and pipets are measured, cut off to the proper lengths, fire-polished, and mounted with proper rubber connections. For this purpose heavy 3 mm. bore pressure tubing is used, except on the lower part of the potash (16) and pyro (21) pipets where black sulphid-free tubing is necessary. The pressure tubing must be thoroughly cleaned of its talc. A piece of tubing (10) of 1 mm. bore and 30 cm. long, connected at each end by 1 mm. bore glass tubing to two pieces of the 3 mm. bore pressure tubing, is attached at one end to the arm of the sampling tap (9). Finally, the various parts are supported by appropriately placed 2-inch screws, covered with rubber tubing, and held firmly by copper wire covered with rubber tubing. The taps must not be allowed to rest on or press against the Haldane board, as they are thereby loosened from their bores, causing them to leak. Care should be taken not to fasten the glass parts too rigidly, as with changes in temperature the glass may break. In case the level markings are not cut into the glass on the potash and pyro pipets and manometer tube a linen thread may be tightly tied on and held in place by a tiny drop of glue on either side. The line drawings and photographs (Figs. 11, 12) indicate quite accurately the general set up and position of the supporting screws, clamps, and so forth.

A convenient way of cutting glass tubing the size of the water-bath or even larger is to use an electric glass cutter (Fig. 13). It consists of 2 or 3 feet of nichrome or chromel wire (No. 22 or 24, B. & S.) supported by three or four 2-inch screws as binding-posts on an asbestos board. To the binding-post at one end is attached one of the wires from an ordinary electric circuit; to the binding-post at the other end is fastened another piece of nichrome wire

about 18 inches long to the free end of which is attached an ordinary thumb snap switch which is connected with the other insulated wire from the electric circuit. When the current is on the

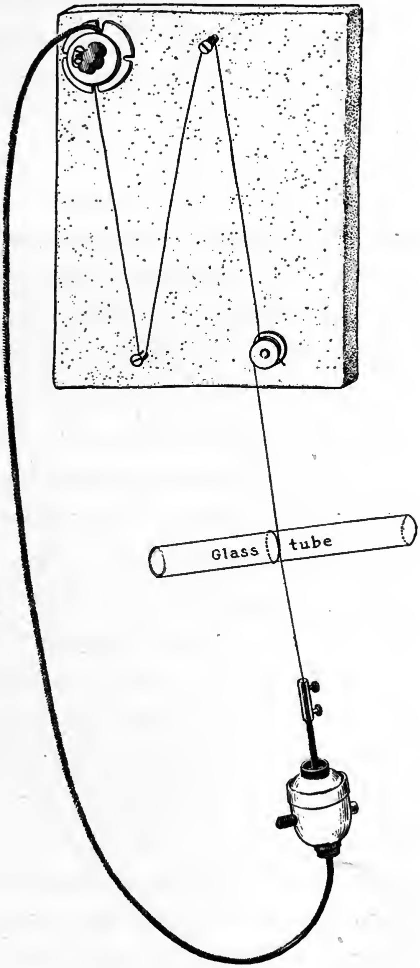

Fig. 13.—Electric glass cutter.

wire should become red hot, but should not reach a white heat; the proper degree of heating is regulated by varying the length of the nichrome wire between the binding-posts. A single deep cut

is made on the glass tubing with a sharp triangle file and the nichrome wire is passed through this cut and around the tube. The wire must be kept taut and no short circuit made by contact between the loops of wire. The switch, which acts as a handle, is pressed with the thumb, the wire becomes red hot, and expands. It is necessary, therefore, to keep sufficient tension on the wire to take up the slack. After thirty to sixty seconds the tube will crack off evenly. With very hard glass it may be occasionally necessary to turn off the electricity and dash on a glass of cold water.

4. **Control Tube.**—By means of the control tube, first employed in gas analysis by Williamson and Russell in 1868, the effects of changes in temperature, pressure, and water vapor on the gas volume may be compensated. The control tube (3) has approximately the same shape and volume as the gas buret; it is sealed at the lower end and filled about half-way up its stem with distilled water. It is placed in the water-bath beside the buret and the pressure of the air within is balanced against that in the buret through the potash absorption pipet (16), the potash tube (25) acting as a manometer. A three-way tap (18) on the control tube permits connection with the room air, so that before an analysis the pressure in the control tube may be made the same as that in the room. Since the control tube is in the water-bath (1) beside the buret any changes in pressure or temperature will affect alike the air in both the buret and the control tube, and their effect on the air in the buret can be compensated by altering the level of the potash reservoir (17) and the mercury reservoir (6) to bring the potash to the standard level in the manometer (25) and in the potash pipet (15), thereby maintaining the volume of air in the control tube constant and the pressure in the control tube and buret alike. Therefore the readings of the buret are compensated by mechanical means for variations of temperature and barometric pressure during the analysis.

5. **Management of Haldane Apparatus.**—(*a*) *Preliminary.*—Compressed air is slowly bubbled through the water-bath (1) in which the buret (2) and control tube (3) are mounted to keep the water constantly stirred and thus maintain the entire column of water at a uniform temperature. As a result the air in both the control tube and the buret has the same temperature. Instead of having a constant stream of compressed air circulating through the water-bath the water can be stirred just before any of the readings on the buret are made by using a blood-pressure bulb attached to the tube leading into the water-bath. Before the machine is ready for an analysis it must be checked to see that it is air-tight and that there is no carbon dioxid or oxygen in the buret. For this the following procedure is necessary: The buret tap (8) and the potash tap (14) are turned so that the buret is closed to room air and is in connection with the potash pipet (16). With the control tap (18) open to room air and in connection with the potash manometer (25) and the control tube (3) the levels of the potash in the absorbing pipet (15) and in the manometer tube (25) are set at the levels marked thereon. The control tap (18) is closed to room air. The air in the buret is shunted into the pyro (21) by properly turning the tap (14) and by raising the mercury reservoir (6) attached to the buret. After passing back and forth in the pyro ten times, the air is shunted into the potash pipet in order to remove all traces of oxygen by bringing the air above the potash level to the same composition as the air in the buret. This procedure is called "washing or rinsing" the connections. After rinsing in the potash twice the air is then passed back and forth in the pyro ten times. This procedure, rinsing in the potash and absorption in the pyro, is repeated three times. The preliminary nitrogen reading can now be taken. To do this the pyro is brought to the level (20), and when carefully adjusted the tap (14) is turned so that the air in the buret is in connection with the potash solution only. The levels in the potash

(15) and manometer (25) tubes are now set, using the potash (17) and mercury (6) reservoirs for this. The potash reservoir is adjusted by sliding through its spring clamp and the mercury reservoir by means of a ratchet and pinion (7). The reading of the mercury meniscus is then made with all the precautions mentioned on page 61: to hold the lens properly and to have the eyes on the correct level and the various levels carefully adjusted. The volume is recorded to the nearest 0.001 c.c. An electric light (with a 12-inch Mazda Fostoria bulb) placed behind the Haldane is turned on by the switch (24); the light shining through the glazed glass (4) sharply defines the mercury meniscus so that accurate readings are quickly obtained. The light is immediately turned off when the reading has been made. The potash tube is again washed twice and the air then shunted into the pyro, and, after passing back and forth ten times, the reading of the volume is again determined, setting the various levels described above. If the machine had been left full of nitrogen from the previous analysis these nitrogen readings should now check. If the readings do not check within 0.002 c.c., the process above is repeated until check readings of the volume are obtained, after which the machine is ready for an analysis.

(*b*) *Sampling.*—Connection is made by a 1-mm. bore rubber tubing (10) from the sampling tap (9) to the sampling tube (12). The tap (11) on the sampling tube is opened, care being taken that the sampling tap (9) is closed so that none of the sample can escape. The potash and pyro levels are carefully set and the buret tap is closed to the potash and opened to room air. At this point in the procedure acidified water is put in the buret with a medicine-dropper if it appears dry, for the air sample must be thoroughly saturated with water vapor throughout the analysis. For this purpose distilled water slightly acidified with sulphuric acid is used (about 2 drops of concentrated sulphuric acid in 50 c.c. of distilled water). It is most important to have sufficient water in the buret, enough

so that the inside appears moist and there is a very small amount on the mercury meniscus. If the buret is too dry, readings simulating a leak in the machine will be obtained because of the variation in saturation of the air sample with water vapor. The buret is washed twice with room air, thus diluting the nitrogen and bringing the air in the buret more nearly to the composition of the sample to be analyzed. The index-finger of the left hand is moistened with water and placed on the top of the buret, and with the right hand holding the mercury reservoir (6), and securely supported on the upper edge of the Haldane board, the mercury in the buret is brought up to the buret tap (not into it), the air is allowed to escape slowly from beneath the index-finger, and then the sampling may be started. The sampling tap (9) is cautiously turned by the thumb and middle finger of the left hand to the sampling tube (12) and buret (2), and, since the sample is under positive pressure, it will run into the buret. When 3 c.c. of the sample have passed into the buret the sampling tap (9) is turned off from the sampling tube (12) and the air in the buret is permitted to escape into the room by cautiously allowing it to flow from under the moistened index-finger in position on the top of the buret. The air escapes until the mercury in the buret has reached the buret tap (8). This process must be carried out slowly so that there is no back lash of the mercury which might introduce room air into the buret and so vitiate the sample. This is the first rinsing. Three subsequent rinsings of about 3 c.c. each are cautiously and carefully made without removing the index-finger of the left hand from its position at the top of the buret, and then the sampling tap (9) is completely opened to the buret and sampling tube. The left land is removed from its position at the top of the buret and the right hand slowly lowered and again raised to pass the sample back into the sampling tube. This process is repeated twice and the mercury reservoir (6) then hung on the ratchet at about 9.0 c.c. With the left hand the mer-

cury reservoir (13) on the sampling tube is taken from its holder and lowered, together with the mercury reservoir (6) on the buret, to such a position that the amount of sample in the buret is 9.5 c.c. or more. The mercury reservoir (6) is hung up on the ratchet. Care is taken to level exactly the mercury in the sampling tube (12) and its reservoir so that the air in the buret will be at atmospheric pressure; the tap (11) of the sampling tube is closed and the mercury reservoir of the sampling tube hung up on its rack. The buret tap (8) is then turned to close the connection with the sampling tube and put the air in the buret in connection with the potash tube (16).

(*c*) *Analysis.*—If the mercury levels of the sampling tube (12) and its reservoir have been properly adjusted, the potash levels will change very little when the buret tap (8) is turned into the potash solution (16). The rubber tubing of the potash tube (16) and also the tubing (5) attached to the buret should be pressed gently to see that the potash levels (15, 25) respond, to make certain that the small openings in the taps are not stopped up with grease. The potash levels (15, 25) are set by carefully adjusting the mercury (6) and potash (17) reservoirs, and, with the precautions mentioned above, the total volume of the air sample is read and recorded. A readjustment of the levels is made as quickly as possible after again gently pressing the mercury tube and the rubber potash tube to insure free communication and the check reading of the total volume of air taken.

The air sample is then passed back and forth eight times in the potash solution and a reading of the volume recorded after setting the potash levels with great care. Again the sample of air is passed five times into the potash solution and the check reading made. If the readings do not agree within 0.002 c.c., the procedure is repeated until check readings are obtained. The tap (14) is then turned so that the sample is passed into the pyro about eighteen times. The potash tube by turning tap (14) properly is rinsed

twice and the sample again shunted into the pyro and passed back and forth ten times. This complete procedure is repeated twice again before a reading is taken of the volume. In making a reading the pyro level is set by means of the mercury reservoir (6) and then the tap (14) is turned to the potash tube and the two potash levels (15, 25) set. A check reading is made after rinsing in the potash and again passing the air back and forth in the pyro ten times. A duplicate analysis is made, using, if possible, another Haldane and following the procedure above. A complete analysis and its duplicate follow:

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Haldane No. V.

Reading buret.		Corr.		Corr. reading.		Diff.		Per cent.
9.377								
9.377	+	0.003	=	9.380				
9.137								
9.136	+	0.007	=	9.143	=	0.237	=	2.53% CO_2
7.443								
7.444	+	0.020	=	7.464	=	1.679	=	17.90% O_2

Haldane No. III.

Reading buret.		Corr.		Corr. reading.		Diff.		Per cent.
9.548								
9.548	+	0.004	=	9.552				
9.303								
9.303	+	0.006	=	9.309	=	0.243	=	2.54% CO_2
7.589								
7.579								
7.579	+	0.023	=	7.602	=	1.707	=	17.87% O_2

(*d*) *Care of the Haldane.*—Several of the steps in the analysis and management of the gas analysis apparatus deserve further discussion.

Whenever check readings on carbon dioxid or oxygen absorption cannot be obtained within a reasonable time, the difficulty is usually due to the following causes: A leaky tap from faulty greasing; an insufficiency of water in the buret to saturate the air, or pieces of grease or mercury obstructing the taps or capillary tubing, or inaccuracy in adjusting the levels.

In transferring the sample into the buret the "dead space" of the connections from the sampling tube to the sampling tap and the upper part of the buret are thoroughly rinsed with the sample to be analyzed. After each rinsing the small portion of sample used for this purpose is allowed to escape into the room in the manner described above. The escape of the air must be slow and gradual so as to prevent any back-lash of the mercury. When the sample is taken into the buret it should be transferred slowly, so that the air may become thoroughly saturated with water vapor and also prevent any mercury from sticking to the sides of the buret. The importance of having sufficient acidulated water in the buret must be emphasized. The presence of acid prevents the water from becoming alkaline from contact with the glass buret and, therefore, from absorbing carbon dioxid. When the buret is dry it is impossible to get constant readings; the potash levels change, and the readings, which show a slight continual decrease in the volume of the air, apparently indicate that the machine is leaking. If at this point the sample is allowed to stand for a few minutes in the buret and in connection with the potash solution it will take up moisture and so increase in volume; in this way it is sometimes possible to obtain check readings and so prevent the loss of the analysis. As Haldane states: "If the buret is allowed to become dry very appreciable errors are produced. A sample of pure air will, for instance, probably increase in volume when passed over into the potash pipet, as the air will take up more moisture than it loses of carbon dioxid in contact with the potash solution." An excess of water insures that under all conditions the volume of the gas measured is completely saturated with water vapor, and, therefore, the contractions from absorption of carbon dioxid and oxygen will be proportional to those obtained had the gas been absolutely dry. On the other hand, too much water in the buret decreases the volume of air and so gives incorrect, although constant, readings.

A dirty buret vitiates the analyses, especially the oxygen determination, causing the latter to be appreciably higher, and if very dirty, amounting to an error of 0.10 per cent. If the buret is cleaned before it becomes very dirty the process is much easier. In cleaning, the buret is filled through the top with concentrated nitric acid diluted with an equal amount of distilled water and allowed to stand for one-half hour. The nitric acid is then removed and a long pipe-stem cleaner is very carefully run down the length of the buret. After removing the pipe-stem cleaner the buret is washed thoroughly and repeatedly with distilled water and finally with distilled water containing a few drops of sulphuric acid. A very dirty buret, however, must be cleaned with warm cleaning solution, or concentrated nitric acid, and for this it is necessary to disconnect the rubber tubing (5) and suck the acid up into the buret. Alcohol and ether should never be used for cleaning gas analysis apparatus, because it is very difficult to remove the last traces and their vapor may cause serious analytic errors.

The control tap (18) is closed to room air during an analysis, but on account of changes in the temperature of the room it is often necessary between analyses to open the tap and reset the two potash levels (15, 25) at room air pressure. It is not necessary at this point to get check readings of the nitrogen. There must be free connection between the potash manometer (25) and the control tube (3); otherwise there is no longer a correct compensation for temperature and pressure changes and the analyses will be incorrect; grease in the tap bore is usually the cause of this error. Occasionally during an analysis the temperature changes are such that the range of adjustment of the potash reservoir (17) is insufficient to properly set the level in the manometer tube (25), and to overcome this difficulty potash solution is either added to or removed from the reservoir (17) by means of a capillary pipet.

When through using a machine the control tap (18) should be

opened to room air, manometer, and control tube; otherwise temperature changes may suck the potash up into the taps. The potash tap (14) should also be turned so that the solutions are not in connection with the buret, to prevent them from getting into the taps or buret in case of any accident to the apparatus.

The absorption of the last traces of oxygen is slow and, if the check reading is taken too soon, the readings may be practically unchanged from the preceding reading and yet all the oxygen may not be absorbed; at least two minutes of shaking by the mechanical shaker should be allowed between check readings. The use of tubes in the pyro pipet materially increases the rapidity of the oxygen absorption because of the increased surface area. With their use the pyro, especially when it has become thick from use, is liable to form air bubbles which must be carefully watched for, and the pyro changed as soon as their tendency to develop is noticed. If the pyro is either very new or nearly used up it absorbs the last traces of oxygen very slowly.

Since the liquids are controlled by the movements of the mercury reservoir, it sometimes happens that they are sucked over into the buret. The machine should be cleaned as soon as the accident happens. In such a case the buret and connections must be thoroughly washed first with dilute sulphuric acid (1 part sulphuric to 3 parts distilled water) and finally with distilled water, slightly acidified with sulphuric acid. The presence of the strong alkaline solutions on the taps may cause them to be frozen into their bores, and for this reason they must be carefully cleaned of the alkaline solution.

Sulphid-free black rubber tubing must be used on the potash absorption pipet. The ordinary black tubing contains various sulphur compounds, which are more or less soluble in potash, giving a yellowish tinge to the solution. Such a solution tends to absorb oxygen so that the carbon dioxid reading in consequence will be

too high. It is also better to use this black sulphid-free tubing on the pyro pipet. The rest of the connections which do not come in contact with the absorbing liquids are made with heavy red pressure tubing. The bore of the pressure tubing is covered with talc which should be carefully removed before using to prevent any leaks. To remove the talc the tubing is soaked in soap and water and the bore carefully scrubbed with a pipe-stem cleaner; it should then be thoroughly rinsed in distilled water slightly acidified with sulphuric acid.

Practically the only source of leaks on a Haldane that is carefully set up is due to the improper greasing of the taps. In greasing, the tap and its bore should be thoroughly wiped off with a soft cloth and the tap covered with a very thin layer of grease, avoiding an excess which might clog the openings. When the greased tap is turned in its bore there should be no striations and the tap should turn smoothly. In cleaning the bore pipe-stem cleaners are very satisfactory, but care must be taken not to scratch the glass with the uncovered wire. In manipulating a tap the handle is turned by the thumb and index-finger at the same time pressing gently inward; care, however, must be used not to press too hard, as thereby the grease is squeezed out, causing binding of the tap and so necessitating regreasing. Beginners have a tendency to pull the tap out in turning it and so causing a leak.

(*e*) *Filling the Haldane.*—The solutions in the machine are changed whenever the pyro gives an oxygen content of outdoor air below 20.90 per cent., or whenever the pyro becomes thick and tends to catch air bubbles. The potash solution is readily changed by taking out the taps (14) and (18), and by removing the potash container (17) from its holder, to allow the solution to run out. The pipet is rinsed with dilute hydrochloric acid to dissolve the thin film of carbonate formed, and then repeatedly washed with distilled water. Fresh potash solution of specific gravity 1.15 is

then put in the pipet through the potash reservoir. The potash should stand at the two levels (15) and (25) and half-way up in the stem of the potash reservoir when the latter is placed in its holder. In filling the pyro pipet the tap (19) is taken out and then the solid glass rod (30) is removed from the lower end of the rubber tubing attached to the pipet. By means of a glass funnel and an extra piece of rubber tubing and glass connection the pipet (21) is thoroughly cleaned with water and finally filled to its proper level with the pyro solution, and the solid glass rod is reinserted in the end of the rubber tube. It is not necessary to change the potash solution in the seal, although water must be added from time to time to replace that lost by evaporation, and so prevent breaking of the seal. The buret should be thoroughly cleaned whenever the solutions are changed. The water-bath should be kept clean and completely filled with distilled water. If the bulbs of the buret or control tube are only partly covered with water, temperature changes will affect the readings of the air volume. About 20 c.c. of mercury are introduced into the buret through the reservoir (6) attached to the buret by means of rubber tubing (5). The mercury should be changed whenever it becomes dirty.

6. **Analysis of Outdoor Air.**—The limit of accuracy attainable by a skilled analyst using a Haldane gas analysis apparatus with a perfectly clean buret is ±0.01 per cent. In routine work, however, this error increases to ±0.03 per cent. for oxygen. In all work done in our laboratory analyses are made in duplicate and must agree in the carbon dioxid determination within ±0.02 per cent. and in the oxygen determination within ±0.03 per cent of the average.

Haldane has found with this apparatus that outdoor air contains 0.03 per cent. carbon dioxid and 20.93 per cent. oxygen, and with his large apparatus the carbon dioxid was 0.030 per cent. and the oxygen 20.928 per cent. Benedict[7] found that the average result of 212 analyses of out-door air using the Sondén apparatus

was 0.031 per cent. carbon dioxid and 20.938 per cent. oxygen, the balance being due to nitrogen and inert gases. In one series of 349 analyses of out-door air nearly equally divided among 18 Haldane gas analysis apparatus which had been calibrated in duplicate by mercury, as described on page 60, we found the average carbon dioxid content to be 0.037 per cent. and the oxygen content 20.930 per cent. In a second series of 343 analyses the average carbon dioxid was 0.035 per cent. and the average oxygen 20.930 per cent. The average of the two series of 692 analyses was 0.036 per cent. for carbon dioxid and 20.930 per cent. for oxygen. The outdoor air for these analyses was taken from the fire escape outside the laboratory window and in the center of Rochester, Minnesota. On account of the large number of chimneys in the neighborhood varying amounts of smoke drifted toward the laboratory; this probably accounts for the differences in the carbon dioxid and oxygen percentages found by us as compared with the results obtained both by Haldane and Benedict. Therefore in our calculations and in Table III of the Appendix we have adopted as an average for outdoor air 0.04 per cent. of carbon dioxid and 20.93 per cent. of oxygen. Room air, however, has a variable composition (page 41) with an increase in the carbon dioxid and a corresponding decrease in the oxygen content, the variations depending mainly on the size of the room, the number of occupants, and the efficiency of the ventilating system. As a routine procedure an outdoor air analysis is done once a week on every Haldane machine and a record kept on file. We consider it essential that such control air analyses be made regularly to indicate the accuracy of the apparatus, the efficiency of the absorbing solutions, and the skill of the analyst (Form IV, Appendix).

7. **Shaker.**—When many analyses are being done, using several machines, some mechanical device should be used to raise and lower the mercury reservoirs (6). For this purpose we have beside

each of our 18 Haldanes an arm (28) about 12 inches long which rises and falls at its outer end from 3½ to 4 inches ten to twelve times a minute. This arm is driven by light shafting (27) from an eccentric geared down from a one-sixth horse-power electric motor. The exact throw for each Haldane is obtained by varying the position of the hook (26) on the arm upon which the mercury reservoir is hung. The level of the arm (28) is adjusted by a thumb-screw by means of which it is clamped to the shafting (27). The most efficient throw is one which keeps the mercury in the bulb, never in the stem of the buret. While a single analysis cannot be done as quickly by this method as by hand, it allows one person to run from four to six machines and at the same time to calculate the analyses. An experienced analyst can thus do from twelve to sixteen complete analyses and their calculations in a morning.

D. SOLUTIONS

1. **Potassium Pyrogallate Solution (Haldane).**—To 600 gm. of stick potassium hydroxid (not purified by alcohol) are added 300 c.c. of distilled water. The specific gravity of the resulting solution should be exactly 1.55 (this can be determined by using a hydrometer or by finding the weight of 100 c.c. of the solution, which should be 155 gm.). If the specific gravity is too low, potassium hydroxid should be added until the desired concentration is obtained. To 100 c.c. of this concentrated potash solution 10 gm. of Merck's pyrogallic acid are added in a bottle with a greased stopper. Haldane states that the solution should be made exactly in the manner described. The resulting solution of potassium pyrogallate should have a brownish-green tint and should become a deep wine color immediately on exposure to air. The pyro should be at least a month old before using, although it improves with greater age. This "aging" can sometimes be hastened by exposing the pyro for a few minutes to air and thus giving it a "start."

2. **Potash Solution for Carbon Dioxid Absorption.**—For the absorption of carbon dioxid we use a dilute solution of potassium hydroxid of specific gravity of about 1.15, approximately a 17 per cent. solution.

3. **Black Rubber Grease.**—Ordinary black rubber tubing of small diameter is washed in water to remove the talc. Then it is cut into very small pieces and slowly added to an equal quantity of lanolin which has been melted (about 2 tablespoonfuls of finely cut tubing and of lanolin). The rubber is allowed to melt, using a slow flame until the resulting liquid is free from any lumps. The grease should be very smooth and of a consistency slightly firmer than lanolin. While still melted the grease is poured into a small "cold cream" jar. It is a very satisfactory grease for glass taps, it wears well, and if sufficiently thin it will not clog the tap.

4. **Cleaning Solution.**—This should be used to remove grease from glass apparatus like the sampling tubes and occasionally the buret of the Haldane. It is a supersaturated solution of potassium bichromate in concentrated sulphuric acid. It is more efficient when warm and can be used over and over until the solution has become green, when it should be discarded.

5. **Cleaning Mercury.**—The mercury used in the type of gas analysis described becomes very dirty from grease, dust, and from forming an amalgam with the copper wire used to wire the connections of the Haldane and sampling tubes. In cleaning, the mercury should be first wrung through several layers of close meshed towels. It is then covered with nitric acid (1 part concentrated nitric acid to 1 part distilled water) and air bubbled through it for several hours. The same procedure is repeated, using distilled water, so that the mercury is no longer acid. The excess water is removed with filter-paper and the mercury is allowed to stand until all the water has evaporated, leaving the mercury dry.

SECTION III

CALCULATION OF BASAL METABOLIC RATE

WHILE the patient is in the laboratory the following data are obtained: The gasometer readings at the start and at the end of the test, and the duration of the test in minutes and seconds; the temperature of the expired air at the time of the final volumetric readings and the barometric pressure, and finally, the patient's height, weight, pulse, and blood-pressure. A detailed calculation of the basal metabolic rate step by step is given below. On Form II, Appendix, is shown a routine calculation in the same case in which our forms and calculation tables devised to simplify the procedure are used.

1. Volume of Expired Air.

5–14–18. Case A 172,918; F. 50; wt. 53.7 kg.; ht. 159.4 cm.
Barometer 738.8 mm. Temperature gasometer 21.6° C.

	I.	II.
Gasometer reading at end.......	63.90 cm.	65.90 cm.
Gasometer reading at start......	1.50 cm.	3.50 cm.
Gasometer difference..	62.40 cm.	62.40 cm.

Since by calibration we have found that a rise of 1 cm. on the steel tape corresponds to 1.256 l. (the factor of the gasometer), the volume of the expired air is

62.4 cm. × 1.256 = 78.38 l. at 738.8 mm. and 21.6° C.

In order to compare the volumes of gases with each other, a standard pressure and temperature have been universally adopted, and the volumes of all gases are expressed under the standard conditions at a pressure of 760 mm. of mercury and at a temperature of 0° C. (or at absolute temperature 273°+ 0° C.) and dry.[32] The gas volume, 78.38 l., has, therefore, to be reduced to standard

conditions of temperature and pressure. To do this the following steps are necessary, and the various factors are obtained from Landolt, Bornstein, and Roth:

2. **Correction of Barometer to 0° C.**—The barometer reading must first be corrected for the temperature of the mercury, since the density of the mercury varies with variations in temperature. The temperature of the barometer is 21.6° C., and at this temperature the correction for the density of mercury for a barometer reading recorded on a brass scale is 2.6 mm. The corrected barometer reading is 738.8 mm. — 2.6 mm. = 736.2 mm.

3. **Correction for Water Vapor.**—The expired air is saturated with water vapor; therefore the volume of the air, if dry, would be smaller. The pressure of water vapor for the temperature at which the volume is read must be deducted from the barometer reading. At the temperature of 21.6° C. this correction is 19.4 mm. Consequently the pressure of the dry expired air is 736.2 mm. − 19.4 mm. = 716.8 mm.

4. **Reduction to Standard Pressure.**—According to Boyle's law the volume of a gas is inversely proportional to the pressure, provided the temperature remains constant. To correct to the standard pressure of 760 mm. the following procedure is necessary:

$$78.38 : x = 760 : 716.8$$

$$\text{or } 78.38 \times \frac{716.8}{760} = 73.93 \text{ l. at 760 mm. and 21.6° C., dry.}$$

5. **Reduction to Standard Temperature.**—Charles' law states that, provided the pressure remains constant, the volume of a gas will change $\frac{1}{273}$ of its volume at 0° for each degree of change of temperature. To reduce the above gas volume to standard temperature the following calculation must be done:

$$73.93 : x = 273 + 21.6 : 273 + 0$$

$$\text{or } 73.93 \times \frac{273 + 0}{273 + 21.6} = 68.52 \text{ l. at 760 mm. and 0° C., dry.}$$

6. **Ventilation Rate.**—This volume at standard pressure and temperature dry has been expired by the patient in 11 minutes and 4 seconds (or 11.07 minutes). The volume per minute or, as it is called, the ventilation rate per minute is, therefore,

$$\frac{68.52 \text{ l.}}{11.07 \text{ min.}} = 6.19 \text{ l. per minute.}$$

7. **Carbon Dioxid Production.**—Duplicate analyses show that the expired air from the above test contained

3.00 per cent. CO_2
17.53 per cent. O_2
79.47 per cent. N_2

Outdoor air has the following composition (page 78):

0.04 per cent. CO_2
20.93 per cent. O_2
79.03 per cent. N_2 (including all the inert gases).

The carbon dioxid produced by the patient per minute is, therefore,

$$\frac{3.00 - 0.04}{100} \times 6.19 \text{ l.} = 0.183 \text{ l. or } 183 \text{ c.c.}$$

8. **Oxygen Absorption.**—The volume of oxygen absorbed is more difficult to calculate than the carbon dioxid elimination, since the inspired air during the process of respiration has decreased in volume due to the fact that more oxygen has been absorbed from it than carbon dioxid has been given off. From a comparison of the analyses of the expired with the inspired air it will be seen that the nitrogen readings have changed, the nitrogen of the expired air being larger, although nitrogen is in no way involved in physiologic processes, and should, therefore, remain unchanged. Since nitrogen is neither taken up nor given off in respiration, it is evident that for

every 100 volumes of expired air there corresponded in the inspired air not 20.93 volumes of oxygen, but

$$20.93 \times \frac{79.47}{79.03} = 21.05 \text{ volumes.}$$

Hence the oxygen absorption is

$$\frac{21.05 - 17.53}{100} \times 6.19 \text{ l.} = 0.218 \text{ l. or } 218 \text{ c.c.}$$

If instead of outdoor air the patient inspires room air it is obvious that the figures found on analysis of the latter must be substituted in those places where the composition of the inspired air enters into the calculation. The values for the correction of the inspired oxygen percentage given in Table III can be utilized by subtracting from them the difference between the percentage of oxygen in outdoor air (20.93) and the percentage of oxygen in the inspired room air.

9. **Respiratory Quotient.**—The respiratory quotient is the ratio between the volume of the carbon dioxid produced and the corresponding volume of oxygen absorbed,

$$\text{or } \frac{183 \text{ c.c. } CO_2}{218 \text{ c.c. } O_2} = 0.84, \text{ the respiratory quotient.}$$

The respiratory quotient when not affected by abnormal respiration indicates the kind of material being burned in the body. Thus when pure carbohydrate is burned the reaction is

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O$$

And the ratio of the volume of carbon dioxid produced to the volume of oxygen absorbed is

$$\frac{6CO_2}{6O_2} = 1.00$$

For protein the respiratory quotient is 0.80 and for fat 0.71, and for a mixed diet consisting of all three substances the quotient will average about 0.84. It is necessary to know the value of the respiratory quotient since the calorific value of 1 liter of oxygen is 5.047 when the respiratory quotient is 1.00, but is only 4.690 when the respiratory quotient is 0.71. Consequently, the number of calories produced when 1 liter of oxygen is absorbed will depend on the food substances being burned.

10. **Calories per Square Meter per Hour.**—For a quotient of 0.84 the calorific value of 1 liter of oxygen is 4.850 (using the value for the non-protein respiratory quotient, a negligible error which will be explained later). Therefore, the number of calories produced per hour will be

$$0.218\text{ l.} \times 60\text{ min.} \times 4.850\text{ cal.} = 63.4\text{ cal. per hour.}$$

Du Bois has shown that the heat production is proportional to the surface area. From Du Bois' height-weight chart the surface area corresponding to a height of 159.4 cm. and a weight of 53.7 kg. is 1.54 sq. m. The number of calories produced per square meter of body surface per hour is

$$\frac{63.4\text{ cal.}}{1.54\text{ sq. m.}} = 41.2\text{ cal. per sq. m. per hour.}$$

11. **Basal Metabolic Rate (B. M. R.).**—The normal standard for a woman aged fifty is 35.0 cal.; therefore, this patient has a basal metabolic rate of

$$\frac{41.2 - 35.0}{35.0} = +18\text{ per cent.}$$

12. **Checking Calculations.**—In order to avoid technical errors all original observations are made by two independent sets of readings, as will be noted throughout the description of the technic, and checked by a second observer. The calculations are carried

out as on Forms I and II of the Appendix, and completely checked by a second calculator before the results are reported. The following morning all the calculations of the previous day are rechecked by a third calculator.

13. **Non-protein Respiratory Quotient.**—The calorific value of 1 liter of oxygen when protein is burned is 4.485; when fat is burned, 4.686; when carbohydrate is burned, 5.047. To apportion the quantity of heat derived from the combustion of protein, fat, and carbohydrate the following additional steps are necessary: The amount of heat produced from protein can be calculated if the total nitrogen in the urine is known, because every gram of nitrogen appearing in the urine indicates a heat production of 26.51 cal., during which process 5.91 l. of oxygen are consumed and 4.76 l. of carbon dioxid given off. To obtain the amount of heat by the method of indirect calorimetry resulting from the combustion of fat and carbohydrate the amount of carbon dioxid and oxygen due to protein combusion must be subtracted from the respiratory carbon dioxid and oxygen, and the oxygen difference then multiplied by the calorific value of oxygen for the resultant respiratory quotient from the combustion of fat and carbohydrate (non-protein respiratory quotient). The total metabolism will be the sum of the heat produced by the combustion of protein added to that from the combustion of carbohydrate and fat.

Magnus-Levy has shown that the calculation of the protein and non-protein heat separately rarely makes a difference of 3 per cent. in the amount of heat found by neglecting this refinement and calculating directly the heat from the average respiratory quotient and total carbon dioxid elimination and oxygen consumption. Furthermore, the inability to obtain exact urinary nitrogen determinations for short periods such as used in indirect calorimetry renders the refinement of questionable value. Therefore in all our calculations we neglect this step.

A complete calculation from the protein and non-protein factors to obtain the non-protein respiratory quotient and to apportion[55] the heat due to the combustion of protein, fat, and carbohydrate in the case given above is as follows:

CO_2 = 183 c.c. per min. or 10.98 l. per hour.
O_2 = 218 c.c. per min. or 13.08 l. per hour.
Urinary nitrogen per hour = 0.333 gm.
Non-protein CO_2 per hour = 10.98 l. — (0.333 × 4.76) = 9.39 l.
Non-protein O_2 per hour = 13.08 l. — (0.333 × 5.91) = 11.11 l.

$$\text{Non-protein respiratory quotient} = \frac{9.39}{11.11} = 0.85.$$

Calories derived from protein combustion = 0.333 × 26.51 = 8.83
Calories derived from non-protein combustion = 11.11 × 4.863 = 54.03

Total calories per hour = 62.86

$$\text{Calories per square meter per hour} = \frac{62.86}{1.54} = 40.8.$$

$$\text{Basal metabolic rate} = \frac{40.8 - 35.0}{35.0} = +17 \text{ per cent.}$$

Combustion due to carbohydrate = 54.03 × 49 per cent. = 26.48 cal.
Combustion due to fat = 54.03 × 51 per cent. = 27.55 cal.
Combustion due to protein = 8.83 cal.

14. **Calculation of Metabolic Rate of a Diabetic.**—The calculation of the metabolic rate of a diabetic is much more difficult. The diabetic organism is more or less unable to burn sugar, depending on the severity of the disease. The relation between the urinary nitrogen and sugar elimination in the fasting and meat-fed diabetic, the dextrose (D) to nitrogen (N) ratio, is the key to the quantity of sugar which can be derived from protein metabolism. Allen and Du Bois have given the calculation of the metabolism of a diabetic when there is sugar formation from protein—the details of which are given below:

"In the normal metabolism each gram of nitrogen in the urine indicates the combustion of 6.25 gm. protein, with the liberation from this protein of 26.51 cal., 9.35 gm. carbon dioxid, and the absorption of 8.45 gm. oxygen. It is obvious that if part of this pro-

tein molecule is unoxidized in the diabetic organism and is excreted in the urine, all of these figures will be lowered by exactly the number of calories and grams of carbon dioxid and oxygen lost in the glucose. With the dextrose-nitrogen ratio of 3.65 to 1, 1 gm. of nitrogen in the urine indicates the combustion of 6.25 gm. protein with the liberation of 26.51 minus 13.47 cal., 9.35 minus 5.35 gm. carbon dioxid, and the absorption of 8.45 minus 3.89 gm. oxygen. When the dextrose-nitrogen ratio is lower, the calculation is easily made, as follows: The calories, carbon dioxid, and oxygen ascribed to the metabolism of protein are calculated from the number of grams of nitrogen excreted per hour by using the normal factors given by Lusk.[76] Knowing the number of grams of glucose excreted per hour, one can make the proper subtractions, since each gram of glucose represents a loss of 3.692 cal., 1.467 gm. carbon dioxid, and 1.067 gm. of oxygen. In this way it is possible to determine the non-protein respiratory quotient and the heat production by the method of indirect calorimetry. If there is no glycosuria, or if the sugar in the urine is all derived from ingested carbohydrate, the calculations are exactly the same as for normal persons."

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APPENDIX

EXPLANATION OF TABLES

A CALCULATION of the basal metabolic rate is appended (Forms I, II). The form adopted by us involves the use of tables which we have compiled to simplify the calculations detailed above.

Table I.—The duration of the test is recorded in minutes and to the nearest second, and used in the calculations as minutes and decimal parts of a minute. Table I is used to convert seconds into decimal parts of a minute.

Table I.

Equivalent of Seconds in Decimal Parts of a Minute.

Sec.	Min.	Sec.	Min.	Sec.	Min.
1	0.02	21	.35	41	.68
2	.03	22	.37	42	.70
3	.05	23	.38	43	.72
4	.07	24	.40	44	.73
5	.08	25	.42	45	.75
6	.10	26	.43	46	.77
7	.12	27	.45	47	.78
8	.13	28	.47	48	.80
9	.15	29	.48	49	.82
10	.17	30	.50	50	.83
11	.18	31	.52	51	.85
12	.20	32	.53	52	.87
13	.22	33	.55	53	.88
14	.23	34	.57	54	.90
15	.25	35	.58	55	.92
16	.27	36	.60	56	.93
17	.28	37	.62	57	.95
18	.30	38	.63	58	.97
19	.32	39	.65	59	.98
20	.33	40	.67	60	1.00

Table II.—In this table are given the log factors for converting in one step the gas volumes to standard temperature and pressure, dry, including the correction of the observed barometer readings for the variations in the density of mercury from changes in temperature. The table gives the factors for a barometric range from 700 to 780 mm. and for temperatures between 15.0° and 32.0° C.

As an example the derivation of the factor used in the experiment given in the preceding pages is as follows:

Barometer = 738.8 mm. = 739 mm.

Temperature of the barometer = temperature of the gasometer = 21.6° (21.5°). We assume the temperature of the barometer to be the same as the temperature of the gasometer; as they are in adjoining rooms, the error thus introduced is negligible and the calculation greatly simplified (a variation of 2 degrees causes a change of only 0.1 mm. in the correction). The barometer reading is corrected for the density of mercury at 21.5° C. thus:

739.0 mm.
  2.6 mm. correction for density of mercury

736.4 mm. corrected barometer.

The vapor tension of water at 21.5° C. is 19.2 mm. and must be subtracted from the corrected barometer reading to get the pressure of the air dry.

736.4 mm.
  19.2 mm.

717.2 mm. = 717 mm.

In reducing the gas volume from 21.5° to 0° C. it is necessary to multiply the gas volume by the ratio $\frac{273 + 0}{273 + 21.5}$. The logarithm of this ratio is 0.96702–1 as given by Landolt, Börnstein, and Roth. In the same way the volume is reduced to standard barometric pressure by multiplying it by the ratio $\frac{717}{760}$, the log of which ratio is 0.97471–1. We have combined these log factors for the correction of the temperature and pressure into one, thus:

0.96702–1
0.97471–1

1.94173–2 or 0.94173–1

The log factor for the experimental data of 738.8 mm. (739) and 21.6° (21.5°) combining (1) the correction for the density of mercury,

Table II.

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure,Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	700	701	702	703	704	705	706	707	708	709	710
15.0	$\bar{1}$.9319	9325	9331	9338	9344	9351	9357	9363	9369	9375	9382
15.5	9308	9314	9320	9327	9333	9340	9346	9352	9359	9365	9372
16.0	9298	9304	9310	9317	9323	9329	9335	9341	9348	9354	9361
16.5	9287	9293	9299	9306	9312	9318	9324	9330	9337	9343	9350
17.0	9277	9283	9289	9296	9302	9308	9314	9320	9327	9333	9340
17.5	9266	9272	9278	9284	9290	9297	9303	9309	9316	9322	9329
18.0	9255	9261	9267	9273	9279	9286	9292	9298	9305	9311	9318
18.5	9244	9250	9256	9262	9268	9275	9281	9287	9294	9300	9307
19.0	9233	9239	9245	9251	9257	9264	9270	9276	9283	9289	9296
19.5	9222	9228	9234	9240	9246	9253	9259	9265	9271	9278	9285
20.0	9211	9217	9223	9230	9236	9242	9248	9254	9260	9266	9273
20.5	9200	9206	9212	9218	9224	9230	9236	9242	9248	9255	9262
21.0	9188	9194	9200	9206	9212	9219	9225	9231	9237	9243	9251
21.5	9176	9182	9188	9194	9200	9207	9213	9219	9225	9232	9239
22.0	9164	9171	9177	9183	9189	9196	9202	9208	9214	9221	9228
22.5	9152	9159	9166	9172	9178	9185	9191	9197	9203	9210	9217
23.0	9141	9147	9153	9159	9166	9173	9179	9186	9192	9198	9205
23.5	9129	9135	9141	9147	9154	9161	9167	9173	9179	9186	9193
24.0	9117	9123	9129	9135	9142	9149	9155	9161	9167	9174	9181
24.5	9105	9111	9117	9123	9130	9137	9143	9149	9155	9162	9169
25.0	9093	9099	9105	9111	9118	9125	9131	9137	9143	9150	9157
25.5	9080	9086	9092	9098	9105	9112	9118	9124	9130	9137	9144
26.0	9068	9074	9080	9086	9093	9100	9106	9112	9118	9125	9132
26.5	9056	9062	9068	9074	9081	9088	9094	9100	9106	9113	9120
27.0	9044	9050	9056	9062	9069	9076	9082	9088	9094	9101	9108
27.5	9030	9037	9043	9050	9056	9062	9068	9074	9080	9087	9094
28.0	9017	9023	9029	9035	9042	9049	9055	9061	9067	9074	9081
28.5	9004	9010	9016	9022	9029	9036	9042	9048	9054	9061	9068
29.0	8991	8997	9003	9009	9016	9023	9029	9035	9041	9048	9055
29.5	8977	8983	8989	8995	9002	9009	9015	9021	9027	9034	9041
30.0	8964	8970	8976	8982	8989	8996	9002	9008	9014	9020	9027
30.5	8950	8956	8962	8968	8975	8982	8988	8994	9000	9007	9014
31.0	8937	8943	8949	8955	8962	8969	8975	8981	8987	8994	9001
31.5	8923	8929	8935	8941	8948	8955	8961	8967	8973	8980	8987
32.0	8910	8916	8922	8928	8935	8942	8948	8954	8960	8967	8974

(2) for aqueous vapor, (3) for barometric pressure, and (4) for temperature is 0.9417–1.

As shown above, the patient expired 78.38 liters at the experimental temperature and pressure. To reduce the volume to 0° and

Table II (Con't.)

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure, Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	710	711	712	713	714	715	716	717	718	719	720
15.0	$\bar{1}$.9382	9388	9394	9400	9406	9413	9419	9425	9431	9437	9444
15.5	9372	9377	9384	9389	9396	9403	9409	9415	9421	9426	9433
16.0	9361	9367	9373	9379	9385	9392	9398	9404	9410	9416	9423
16.5	9350	9356	9362	9368	9374	9381	9387	9393	9399	9405	9412
17.0	9340	9346	9352	9358	9364	9371	9377	9383	9389	9395	9402
17.5	9329	9335	9341	9347	9353	9360	9366	9372	9378	9384	9391
18.0	9318	9324	9330	9336	9342	9349	9355	9361	9367	9373	9380
18.5	9307	9313	9319	9325	9331	9338	9344	9350	9356	9362	9369
19.0	9296	9302	9308	9314	9320	9327	9333	9339	9345	9351	9358
19.5	9285	9291	9297	9303	9309	9316	9322	9328	9334	9340	9347
20.0	9273	9279	9285	9291	9298	9305	9311	9317	9323	9329	9336
20.5	9262	9268	9274	9280	9287	9294	9300	9306	9312	9318	9325
21.0	9251	9257	9263	9269	9275	9282	9288	9294	9300	9306	9313
21.5	9239	9245	9251	9257	9263	9270	9276	9282	9288	9294	9301
22.0	9228	9234	9240	9246	9252	9259	9265	9271	9277	9283	9290
22.5	9217	9223	9229	9235	9241	9248	9254	9260	9266	9272	9279
23.0	9205	9211	9217	9223	9229	9236	9242	9248	9254	9260	9267
23.5	9193	9199	9205	9211	9217	9224	9230	9236	9242	9248	9256
24.0	9181	9187	9193	9199	9206	9212	9218	9224	9230	9237	9244
24.5	9169	9175	9181	9187	9194	9200	9206	9212	9218	9225	9232
25.0	9157	9163	9169	9175	9181	9188	9194	9200	9206	9213	9220
25.5	9144	9150	9156	9162	9169	9176	9182	9188	9194	9200	9207
26.0	9132	9138	9144	9150	9157	9164	9170	9176	9182	9188	9195
26.5	9120	9126	9132	9138	9145	9152	9158	9164	9170	9176	9183
27.0	9108	9114	9120	9126	9133	9140	9146	9152	9158	9164	9171
27.5	9094	9100	9106	9112	9119	9126	9132	9138	9144	9151	9158
28.0	9081	9087	9093	9099	9106	9113	9119	9125	9131	9138	9145
28.5	9068	9074	9080	9086	9093	9100	9106	9112	9118	9125	9132
29.0	9055	9061	9067	9073	9080	9087	9093	9099	9105	9112	9119
29.5	9041	9047	9054	9061	9067	9074	9080	9086	9092	9099	9106
30.0	9027	9033	9040	9047	9054	9061	9067	9073	9080	9087	9093
30.5	9014	9020	9026	9033	9040	9047	9053	9059	9065	9072	9079
31.0	9001	9008	9015	9021	9027	9034	9040	9046	9052	9059	9066
31.5	8987	8994	9000	9006	9013	9020	9026	9032	9038	9045	9052
32.0	8974	8980	8987	8994	9000	9007	9013	9019	9025	9032	9039

760 the log factor 0.9417–1 is added to the log of 78.38 (0.8944+1), giving the log 0.8361+1, the antilog of which is 68.57 liters. Throughout our calculations we use four place logs without the characteristics.

Table II (Con't.)

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure, Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	720	721	722	723	724	725	726	727	728	729	730
15.0	$\bar{1}$.9444	9450	9456	9462	9468	9474	9480	9486	9492	9498	9505
15.5	9433	9439	9445	9452	9457	9464	9470	9476	9482	9488	9494
16.0	9423	9429	9435	9441	9447	9454	9460	9466	9472	9478	9484
16.5	9412	9418	9424	9430	9436	9443	9449	9455	9461	9467	9473
17.0	9402	9408	9414	9420	9426	9433	9439	9445	9451	9457	9463
17.5	9391	9397	9403	9409	9415	9421	9427	9433	9439	9445	9452
18.0	9380	9386	9392	9398	9404	9410	9416	9422	9428	9434	9441
18.5	9369	9375	9381	9387	9393	9399	9405	9411	9417	9423	9430
19.0	9358	9364	9370	9376	9382	9388	9394	9400	9406	9412	9419
19.5	9347	9353	9359	9365	9371	9378	9384	9390	9396	9402	9409
20.0	9336	9342	9348	9354	9360	9367	9373	9379	9385	9391	9398
20.5	9325	9331	9337	9343	9349	9356	9362	9368	9374	9380	9387
21.0	9313	9319	9325	9331	9337	9344	9350	9356	9362	9368	9375
21.5	9301	9307	9313	9319	9325	9332	9338	9344	9350	9356	9363
22.0	9290	9296	9302	9308	9314	9321	9327	9333	9339	9345	9352
22.5	9279	9285	9291	9297	9303	9310	9316	9322	9328	9334	9341
23.0	9267	9273	9279	9285	9291	9298	9304	9310	9316	9322	9329
23.5	9256	9262	9268	9274	9280	9286	9292	9298	9304	9310	9317
24.0	9244	9250	9256	9262	9268	9274	9280	9286	9292	9298	9305
24.5	9232	9238	9244	9250	9256	9262	9268	9274	9280	9286	9293
25.0	9220	9226	9232	9238	9244	9250	9256	9262	9268	9274	9281
25.5	9207	9213	9219	9225	9231	9238	9244	9250	9256	9262	9269
26.0	9195	9201	9207	9213	9219	9226	9232	9238	9244	9250	9257
26.5	9183	9189	9195	9201	9207	9214	9220	9226	9232	9238	9245
27.0	9171	9177	9183	9189	9195	9202	9208	9214	9220	9226	9233
27.5	9158	9164	9170	9176	9183	9190	9196	9202	9208	9214	9221
28.0	9145	9151	9157	9163	9170	9177	9183	9189	9195	9202	9208
28.5	9132	9138	9144	9150	9157	9164	9170	9176	9182	9188	9195
29.0	9119	9125	9131	9137	9144	9151	9157	9163	9169	9175	9182
29.5	9106	9112	9118	9124	9130	9137	9143	9149	9155	9161	9168
30.0	9093	9099	9105	9111	9117	9124	9130	9136	9142	9148	9155
30.5	9079	9085	9091	9097	9103	9110	9116	9122	9128	9134	9141
31.0	9066	9072	9078	9084	9090	9097	9103	9109	9115	9121	9128
31.5	9052	9058	9064	9070	9076	9083	9089	9095	9101	9107	9114
32.0	9039	9045	9051	9057	9063	9070	9076	9082	9088	9094	9101

Table II (Con't.)

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure,Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	730	731	732	733	734	735	736	737	738	739	740
15.0	$\bar{1}$.9505	9511	9517	9523	9529	9535	9541	9547	9553	9559	9565
15.5	9494	9500	9507	9512	9518	9524	9531	9536	9542	9549	9554
16.0	9484	9490	9496	9502	9508	9514	9520	9526	9532	9538	9544
16.5	9473	9479	9485	9491	9497	9503	9509	9515	9521	9527	9533
17.0	9463	9469	9475	9481	9487	9493	9499	9505	9511	9517	9523
17.5	9452	9458	9464	9470	9476	9483	9489	9495	9500	9507	9513
18.0	9441	9447	9453	9459	9465	9472	9478	9484	9490	9496	9502
18.5	9430	9436	9442	9448	9454	9461	9467	9473	9479	9485	9491
19.0	9419	9425	9431	9437	9443	9450	9456	9462	9468	9474	9480
19.5	9409	9415	9421	9427	9433	9439	9445	9451	9457	9463	9470
20.0	9398	9404	9410	9416	9422	9428	9434	9440	9446	9452	9459
20.5	9387	9393	9399	9405	9411	9417	9423	9429	9435	9441	9448
21.0	9375	9381	9387	9393	9399	9405	9411	9417	9423	9429	9436
21.5	9363	9369	9375	9381	9387	9393	9399	9405	9411	9417	9424
22.0	9352	9358	9364	9370	9376	9382	9388	9394	9400	9406	9413
22.5	9341	9347	9353	9359	9365	9371	9377	9383	9389	9395	9402
23.0	9329	9335	9341	9347	9353	9359	9365	9371	9377	9383	9390
23.5	9317	9323	9329	9335	9342	9348	9354	9360	9366	9372	9379
24.0	9305	9311	9317	9323	9329	9336	9342	9348	9354	9360	9367
24.5	9293	9299	9305	9311	9317	9324	9330	9336	9342	9348	9355
25.0	9281	9287	9293	9299	9305	9312	9318	9324	9330	9336	9343
25.5	9269	9275	9281	9287	9293	9300	9306	9312	9318	9324	9330
26.0	9257	9263	9269	9275	9281	9288	9294	9300	9306	9312	9318
26.5	9245	9251	9257	9263	9269	9276	9282	9288	9294	9300	9306
27.0	9233	9239	9245	9251	9257	9264	9270	9276	9282	9288	9294
27.5	9221	9227	9233	9239	9245	9251	9257	9263	9270	9276	9283
28.0	9208	9214	9220	9226	9232	9238	9244	9250	9256	9262	9268
28.5	9195	9201	9207	9213	9219	9225	9231	9237	9243	9249	9255
29.0	9182	9188	9194	9200	9206	9212	9218	9224	9230	9236	9243
29.5	9168	9174	9180	9186	9192	9199	9205	9211	9217	9223	9229
30.0	9155	9161	9167	9173	9180	9186	9192	9198	9204	9210	9216
30.5	9141	9147	9153	9159	9166	9173	9179	9185	9191	9197	9203
31.0	9128	9134	9140	9146	9153	9160	9166	9172	9178	9184	9190
31.5	9114	9120	9126	9132	9139	9146	9152	9158	9164	9170	9176
32.0	9101	9107	9113	9119	9126	9133	9139	9145	9151	9157	9163

Table II (Con't.)

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure,Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	740	741	742	743	744	745	746	747	748	749	750
15.0	$\bar{1}$.9565	9571	9577	9583	9589	9595	9601	9607	9613	9619	9624
15.5	9554	9560	9566	9572	9579	9584	9590	9596	9602	9608	9614
16.0	9544	9550	9556	9562	9569	9574	9580	9586	9592	9598	9603
16.5	9533	9539	9545	9551	9558	9563	9569	9575	9581	9587	9593
17.0	9523	9529	9535	9541	9547	9553	9559	9565	9571	9577	9583
17.5	9513	9519	9525	9531	9537	9542	9548	9554	9560	9566	9572
18.0	9502	9508	9514	9520	9526	9531	9537	9543	9549	9555	9561
18.5	9491	9497	9503	9509	9515	9521	9527	9532	9538	9544	9550
19.0	9480	9486	9492	9498	9504	9510	9516	9522	9528	9534	9540
19.5	9470	9476	9482	9488	9494	9499	9505	9511	9517	9523	9529
20.0	9459	9465	9471	9477	9483	9488	9494	9500	9506	9512	9518
20.5	9448	9454	9460	9466	9472	9477	9483	9489	9495	9501	9507
21.0	9436	9442	9448	9454	9460	9466	9472	9477	9483	9489	9495
21.5	9424	9430	9436	9442	9448	9455	9461	9467	9473	9479	9485
22.0	9413	9419	9425	9431	9437	9443	9449	9455	9461	9467	9473
22.5	9402	9408	9414	9420	9426	9432	9438	9444	9450	9456	9461
23.0	9390	9396	9402	9408	9414	9420	9426	9432	9438	9444	9450
23.5	9379	9385	9391	9397	9403	9408	9414	9420	9426	9432	9438
24.0	9367	9373	9379	9385	9391	9397	9403	9409	9415	9421	9427
24.5	9355	9361	9367	9373	9379	9385	9391	9397	9403	9409	9415
25.0	9343	9349	9354	9360	9366	9373	9379	9385	9391	9397	9403
25.5	9330	9336	9342	9348	9354	9361	9367	9373	9379	9385	9391
26.0	9318	9324	9330	9336	9342	9349	9355	9361	9367	9373	9379
26.5	9306	9312	9318	9324	9330	9337	9343	9349	9355	9361	9367
27.0	9294	9300	9306	9312	9318	9325	9331	9337	9343	9349	9355
27.5	9283	9289	9295	9301	9307	9313	9319	9325	9331	9337	9342
28.0	9268	9274	9280	9286	9292	9299	9305	9311	9317	9324	9330
28.5	9255	9261	9267	9273	9280	9287	9293	9299	9305	9311	9317
29.0	9243	9249	9255	9261	9267	9274	9280	9286	9292	9298	9304
29.5	9229	9236	9242	9248	9254	9261	9267	9273	9279	9286	9292
30.0	9216	9222	9228	9234	9241	9248	9254	9260	9266	9272	9278
30.5	9203	9209	9215	9221	9227	9234	9240	9246	9252	9258	9264
31.0	9190	9196	9202	9208	9214	9221	9227	9233	9239	9245	9251
31.5	9176	9182	9188	9194	9200	9207	9213	9219	9225	9231	9238
32.0	9163	9169	9175	9181	9187	9194	9200	9206	9212	9218	9225

Table II (Con't.)

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure,Dry: Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	750	751	752	753	754	755	756	757	758	759	760
15.0	$\bar{1}$.9624	9630	9636	9642	9648	9654	9660	9665	9671	9677	9683
15.5	9614	9620	9626	9632	9637	9643	9649	9655	9661	9667	9673
16.0	9603	9609	9615	9621	9627	9633	9639	9645	9651	9656	9662
16.5	9593	9599	9605	9611	9617	9622	9628	9634	9640	9646	9652
17.0	9583	9588	9594	9600	9606	9612	9618	9624	9630	9636	9641
17.5	9572	9578	9584	9590	9595	9601	9607	9613	9619	9624	9630
18.0	9561	9567	9573	9579	9585	9591	9596	9602	9608	9614	9620
18.5	9550	9556	9562	9568	9574	9580	9586	9591	9597	9603	9609
19.0	9540	9546	9551	9557	9563	9569	9575	9581	9587	9593	9598
19.5	9529	9534	9540	9546	9552	9558	9564	9570	9576	9582	9588
20.0	9518	9524	9530	9536	9541	9547	9553	9559	9565	9571	9577
20.5	9507	9513	9518	9524	9530	9536	9542	9548	9554	9560	9566
21.0	9495	9501	9507	9513	9519	9525	9531	9537	9542	9548	9554
21.5	9485	9491	9497	9502	9508	9514	9520	9526	9531	9537	9543
22.0	9473	9479	9485	9491	9497	9503	9509	9515	9521	9526	9532
22.5	9461	9467	9473	9479	9485	9491	9497	9503	9509	9515	9521
23.0	9450	9456	9462	9468	9474	9480	9486	9492	9498	9503	9509
23.5	9438	9444	9450	9456	9462	9468	9474	9480	9486	9492	9498
24.0	9427	9433	9439	9445	9451	9456	9462	9468	9474	9480	9486
24.5	9415	9421	9427	9433	9439	9445	9451	9457	9463	9468	9474
25.0	9403	9409	9415	9421	9427	9433	9439	9445	9450	9456	9462
25.5	9391	9397	9403	9409	9415	9421	9427	9433	9439	9445	9450
26.0	9379	9385	9391	9397	9403	9409	9415	9421	9427	9433	9439
26.5	9367	9373	9379	9385	9390	9396	9402	9408	9414	9420	9426
27.0	9355	9361	9367	9373	9379	9385	9391	9397	9403	9409	9415
27.5	9342	9348	9354	9360	9366	9372	9378	9384	9390	9396	9402
28.0	9330	9336	9342	9348	9354	9360	9366	9372	9377	9383	9389
28.5	9317	9323	9329	9335	9341	9347	9353	9359	9365	9371	9377
29.0	9304	9310	9316	9322	9328	9334	9340	9346	9352	9358	9364
29.5	9292	9298	9304	9310	9316	9322	9328	9334	9340	9346	9351
30.0	9278	9284	9290	9297	9303	9309	9315	9321	9327	9333	9339
30.5	9264	9270	9276	9282	9288	9295	9301	9307	9313	9319	9325
31.0	9251	9257	9263	9269	9275	9282	9288	9294	9300	9306	9312
31.5	9238	9244	9250	9256	9262	9268	9274	9280	9286	9292	9298
32.0	9225	9231	9237	9243	9249	9255	9261	9267	9273	9279	9285

Table II (Con't.)

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure, Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	760	761	762	763	764	765	766	767	768	769	770
15.0	$\bar{1}$.9683	9688	9694	9700	9706	9712	9717	9723	9729	9735	9740
15.5	9673	9678	9684	9690	9696	9702	9707	9713	9719	9725	9731
16.0	9662	9668	9674	9680	9685	9691	9697	9703	9709	9714	9720
16.5	9652	9658	9663	9669	9674	9680	9686	9692	9698	9703	9709
17.0	9641	9647	9653	9659	9665	9670	9676	9682	9688	9694	9699
17.5	9630	9636	9642	9648	9654	9659	9665	9671	9677	9683	9688
18.0	9620	9626	9632	9637	9643	9649	9655	9660	9666	9672	9677
18.5	9609	9615	9621	9626	9632	9638	9644	9650	9655	9661	9667
19.0	9598	9604	9610	9616	9621	9627	9633	9639	9645	9650	9656
19.5	9588	9593	9599	9605	9611	9617	9623	9628	9634	9640	9645
20.0	9577	9582	9588	9594	9600	9606	9612	9618	9623	9629	9635
20.5	9566	9572	9577	9583	9589	9594	9600	9606	9612	9618	9623
21.0	9554	9560	9566	9572	9578	9583	9589	9595	9601	9607	9613
21.5	9543	9549	9555	9561	9567	9573	9578	9584	9590	9596	9602
22.0	9532	9538	9544	9550	9556	9562	9568	9573	9579	9584	9590
22.5	9521	9527	9533	9538	9544	9550	9556	9562	9568	9574	9579
23.0	9509	9515	9521	9526	9532	9538	9544	9550	9556	9562	9567
23.5	9498	9504	9510	9516	9521	9527	9533	9539	9545	9551	9556
24.0	9486	9492	9498	9504	9509	9515	9521	9527	9533	9539	9545
24.5	9474	9480	9486	9492	9498	9503	9509	9515	9521	9527	9533
25.0	9462	9468	9474	9480	9486	9492	9498	9504	9509	9515	9521
25.5	9450	9456	9462	9468	9474	9480	9486	9492	9497	9503	9509
26.0	9439	9445	9451	9457	9463	9468	9474	9480	9485	9491	9497
26.5	9426	9432	9438	9444	9450	9456	9462	9468	9473	9479	9485
27.0	9415	9421	9427	9432	9438	9444	9450	9456	9462	9467	9473
27.5	9402	9408	9414	9420	9426	9432	9438	9444	9450	9455	9461
28.0	9389	9395	9401	9407	9413	9419	9425	9431	9436	9442	9448
28.5	9377	9383	9389	9395	9401	9407	9412	9418	9424	9430	9436
29.0	9364	9370	9376	9382	9388	9394	9400	9406	9411	9417	9423
29.5	9351	9357	9363	9369	9375	9381	9387	9393	9399	9405	9411
30.0	9339	9345	9351	9357	9363	9369	9375	9380	9386	9392	9398
30.5	9325	9331	9337	9343	9349	9355	9361	9367	9373	9379	9385
31.0	9312	9318	9324	9330	9336	9342	9348	9354	9360	9366	9372
31.5	9298	9304	9310	9316	9322	9328	9334	9340	9346	9352	9358
32.0	9285	9291	9297	9303	9309	9315	9321	9327	9333	9339	9345

Table II (Con't.)

Log Factor for Reducing Volume of Gases to Standard Temperature and Pressure, Dry; Including Reduction of Barometric Height to Standard Temperature (brass scale).

Barometer in Millimeters.

Temp. °C	770	771	772	773	774	775	776	777	778	779	780
15.0	$\bar{1}$.9740	9746	9752	9758	9763	9769	9775	9780	9786	9792	9798
15.5	9731	9736	9742	9748	9753	9759	9764	9770	9776	9781	9787
16.0	9720	9726	9732	9737	9743	9749	9755	9760	9766	9772	9777
16.5	9709	9715	9721	9726	9732	9738	9744	9749	9755	9761	9766
17.0	9699	9705	9711	9717	9722	9728	9734	9740	9745	9750	9756
17.5	9688	9694	9700	9706	9711	9717	9723	9729	9735	9740	9746
18.0	9677	9683	9689	9695	9700	9706	9712	9718	9723	9729	9735
18.5	9667	9673	9679	9684	9690	9696	9702	9707	9713	9719	9724
19.0	9656	9662	9668	9674	9679	9685	9691	9696	9702	9708	9714
19.5	9645	9651	9657	9663	9668	9674	9680	9686	9691	9697	9703
20.0	9635	9641	9646	9652	9658	9664	9670	9675	9681	9687	9692
20.5	9623	9629	9635	9641	9647	9652	9658	9664	9670	9675	9681
21.0	9613	9618	9624	9630	9636	9641	9647	9652	9658	9664	9670
21.5	9602	9608	9613	9619	9625	9631	9636	9642	9648	9654	9659
22.0	9590	9596	9602	9608	9613	9619	9625	9631	9636	9642	9648
22.5	9579	9585	9591	9597	9603	9608	9614	9620	9625	9631	9637
23.0	9567	9573	9579	9585	9591	9596	9602	9608	9614	9619	9625
23.5	9556	9562	9568	9573	9579	9585	9591	9596	9602	9608	9614
24.0	9545	9550	9556	9562	9568	9574	9579	9585	9591	9597	9602
24.5	9533	9538	9544	9550	9556	9562	9567	9573	9579	9585	9591
25.0	9521	9527	9533	9539	9545	9550	9556	9561	9567	9573	9579
25.5	9509	9515	9521	9527	9533	9538	9544	9550	9556	9562	9567
26.0	9497	9503	9509	9515	9521	9526	9532	9538	9544	9550	9555
26.5	9485	9491	9497	9503	9509	9514	9520	9526	9531	9537	9543
27.0	9473	9479	9485	9491	9497	9503	9508	9514	9520	9526	9532
27.5	9461	9467	9472	9478	9484	9490	9496	9502	9508	9513	9519
28.0	9448	9454	9460	9466	9472	9478	9483	9489	9495	9501	9506
28.5	9436	9442	9448	9453	9459	9465	9471	9477	9483	9488	9494
29.0	9423	9429	9435	9441	9446	9452	9458	9464	9470	9475	9481
29.5	9411	9417	9423	9428	9434	9440	9446	9452	9458	9464	9469
30.0	9398	9404	9409	9415	9421	9427	9433	9439	9445	9451	9456
30.5	9385	9391	9397	9402	9409	9414	9420	9426	9432	9438	9443
31.0	9372	9378	9384	9390	9396	9401	9407	9413	9419	9425	9430
31.5	9358	9364	9370	9376	9382	9387	9393	9399	9405	9411	9416
32.0	9345	9351	9357	9363	9369	9374	9380	9386	9392	9397	9403

Table III.—The oxygen percentages of the inspired air are corrected to the basis of the expired volume as explained on page 84. The corrected oxygen percentage is equal to $20.93 \times \frac{x}{79.03}$, where x is the percentage of nitrogen of the expired air which is equal to

100 per cent. minus (CO_2 + O_2) per cent. of the expired air. Instead of tabulating the various nitrogen percentages we use the sum of the carbon dioxid and oxygen percentages of the expired air, saving the step of deriving the nitrogen values. In case room air is used the values for the correction of the inspired oxygen percentage given in this table can be utilized by subtracting from them the difference between the percentage of oxygen in outdoor air (20.93) and the percentage of oxygen in the inspired room air.

Table III.

Correction Inspired Oxygen Percentage to Basis of Expired Volume.

CO_2+O_2	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
19.5	21.32	21.32	21.31	21.31	21.31	21.31	21.30	21.30	21.30	21.30
19.6	21.29	21.29	21.29	21.28	21.28	21.28	21.28	21.27	21.27	21.27
19.7	21.27	21.26	21.26	21.26	21.26	21.25	21.25	21.25	21.25	21.24
19.8	21.24	21.24	21.24	21.23	21.23	21.23	21.22	21.22	21.22	21.22
19.9	21.21	21.21	21.21	21.21	21.20	21.20	21.20	21.20	21.19	21.19
20.0	21.19	21.18	21.18	21.18	21.18	21.17	21.17	21.17	21.17	21.16
20.1	21.16	21.16	21.16	21.15	21.15	21.15	21.15	21.14	21.14	21.14
20.2	21.13	21.13	21.13	21.13	21.12	21.12	21.12	21.12	21.11	21.11
20.3	21.11	21.10	21.10	21.10	21.10	21.09	21.09	21.09	21.09	21.08
20.4	21.08	21.08	21.08	21.07	21.07	21.07	21.07	21.06	21.06	21.06
20.5	21.05	21.05	21.05	21.05	21.04	21.04	21.04	21.04	21.03	21.03
20.6	21.03	21.03	21.02	21.02	21.02	21.02	21.01	21.01	21.01	21.00
20.7	21.00	21.00	21.00	20.99	20.99	20.99	20.99	20.98	20.98	20.98
20.8	20.98	20.97	20.97	20.97	20.96	20.96	20.96	20.96	20.95	20.95
20.9	20.95	20.95	20.94	20.94	20.94	20.94	20.93	20.93	20.93	20.93
21.0	20.92	20.92	20.92	20.91	20.91	20.91	20.91	20.90	20.90	20.90
21.1	20.90	20.89	20.89	20.89	20.89	20.88	20.88	20.88	20.87	20.87
21.2	20.87	20.87	20.86	20.86	20.86	20.86	20.85	20.85	20.85	20.85

Table IV.—The logarithms of the calorific values of 1 liter of oxygen are given for various respiratory quotients, plus the log of sixty minutes. We have taken Zuntz and Schumburg's calorie tables and to the log of the various factors given by them have added the log of 60 in order to change in this single process the time period from one minute to one hour. For example, for a non-protein respiratory quotient of 0.85, the calorific value of 1 liter of

oxygen is 4.863, the log of which is 0.68690, and to this is added the log of 60 minutes:

$$
\begin{array}{lcl}
\text{Log } 4.863 & = & 0.68690 \\
\text{Log } 60 & = & \underline{1.77815} \\
 & & 2.46505 = 0.4651 + 2
\end{array}
$$

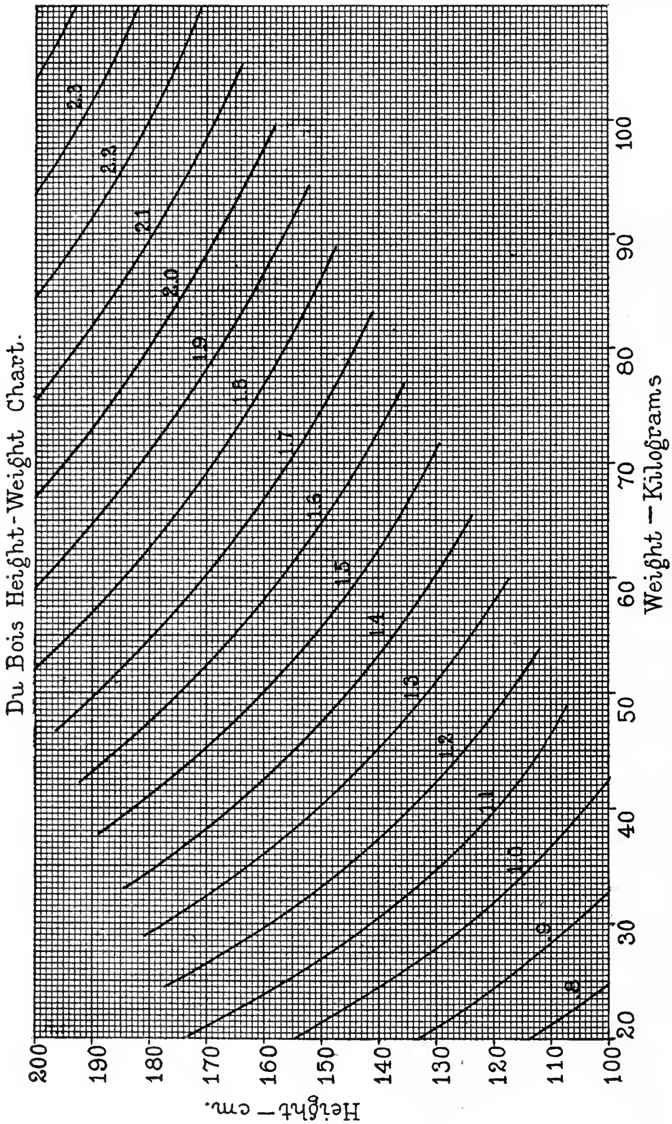
Table IV.

Calorific Value of One Liter of Oxygen for Various (Non-Protein) Respiratory Quotients together with the Log of the Calorific Value to which is Added the Log of 60 Minutes.

R.Q.	Calories for 1 Liter of Oxygen	Log Calories Plus Log 60
0.707	4.686	2.4490
.71	4.690	4494
.72	4.702	4505
.73	4.714	4517
.74	4.727	4528
.75	4.739	4539
.76	4.752	4551
.77	4.764	4562
.78	4.776	4573
.79	4.789	4584
.80	4.801	4596
.81	4.813	4607
.82	4.825	4618
.83	4.838	4629
.84	4.850	4640
.85	4.863	4651
.86	4.875	4662
.87	4.887	4673
.88	4.900	4684
.89	4.912	4695
.90	4.924	4705
.91	4.936	4716
.92	4.948	4727
.93	4.960	4738
.94	4.973	4748
.95	4.985	4759
.96	4.997	4770
.97	5.010	4781
.98	5.022	4791
.99	5.034	4802
1.00	5.047	4813

Table V.—Du Bois "height-weight chart."[34]

Table V.



Du Bois Chart for Determining the Surface Area of Man in Square Meters from Weight in Kilograms (Wt) and Height in Centimeters (Ht) According to the Formula:

Area (sq.cm.) = $Wt.^{.425} \times Ht.^{.725} \times 71.84$

Table VI.—The normal standards for comparison, published by Aub and Du Bois.

Table VI.

Standards of Normal Metabolism
Average Calories Per Hour Per Square Meter of Body Surface (Du Bois).

Age (Years)	Males Cals.	Log Cals.	Females Cals.	Log Cals.
14-16	46.0	1.6628	43.0	1.6335
16-18	43.0	6335	40.0	6021
18-20	41.0	6128	38.0	5798
20-30	39.5	5966	37.0	5682
30-40	39.5	5966	36.5	5623
40-50	38.5	5855	36.0	5563
50-60	37.5	5740	35.0	5441
60-70	36.5	5623	34.0	5315
70-80	35.5	5502	33.0	5185

Table VII.—Four place logarithms.

Table VII.

Four Place Logarithms.

	0	1	2	3	4	5	6	7	8	9	10
1.00	0.0000	0004	0009	0013	0017	0022	0026	0030	0035	0039	0043
1.01	0043	0048	0052	0056	0060	0065	0069	0073	0077	0082	0086
1.02	0086	0090	0095	0099	0103	0107	0111	0116	0120	0124	0128
1.03	0128	0133	0137	0141	0145	0149	0154	0158	0162	0166	0170
1.04	0170	0175	0179	0183	0187	0191	0195	0199	0204	0208	0212
1.05	0212	0216	0220	0224	0228	0233	0237	0241	0245	0249	0253
1.06	0253	0257	0261	0265	0269	0273	0278	0282	0286	0290	0294
1.07	0294	0298	0302	0306	0310	0314	0318	0322	0326	0330	0334
1.08	0334	0338	0342	0346	0350	0354	0358	0362	0366	0370	0374
1.09	0374	0378	0382	0386	0390	0394	0398	0402	0406	0410	0414
1.10	0.0414	0418	0422	0426	0430	0434	0438	0441	0445	0449	0453
1.11	0453	0457	0461	0465	0469	0473	0477	0481	0484	0488	0492
1.12	0492	0496	0500	0504	0508	0512	0515	0519	0523	0527	0531
1.13	0531	0535	0538	0542	0546	0550	0554	0558	0561	0565	0569
1.14	0569	0573	0577	0580	0584	0588	0592	0596	0599	0603	0607
1.15	0607	0611	0615	0618	0622	0626	0630	0633	0637	0641	0645
1.16	0645	0648	0652	0656	0660	0663	0667	0671	0674	0678	0682
1.17	0682	0686	0689	0693	0697	0700	0704	0708	0711	0715	0719
1.18	0719	0722	0726	0730	0734	0737	0741	0745	0748	0752	0755
1.19	0755	0759	0763	0766	0770	0774	0777	0781	0785	0788	0792
1.20	0.0792	0795	0799	0803	0806	0810	0813	0817	0821	0824	0828
1.21	0828	0831	0835	0839	0842	0846	0849	0853	0856	0860	0864
1.22	0864	0867	0871	0874	0878	0881	0885	0888	0892	0896	0899
1.23	0899	0903	0906	0910	0913	0917	0920	0924	0927	0931	0934
1.24	0934	0938	0941	0945	0948	0952	0955	0959	0962	0966	0969
1.25	0969	0973	0976	0980	0983	0986	0990	0993	0997	1000	1004
1.26	1004	1007	1011	1014	1017	1021	1024	1028	1031	1035	1038
1.27	1038	1041	1045	1048	1052	1055	1059	1062	1065	1069	1072
1.28	1072	1075	1079	1082	1086	1089	1092	1096	1099	1103	1106
1.29	1106	1109	1113	1116	1119	1123	1126	1129	1133	1136	1139
1.30	0.1139	1143	1146	1149	1153	1156	1159	1163	1166	1169	1173
1.31	1173	1176	1179	1183	1186	1189	1193	1196	1199	1202	1206
1.32	1206	1209	1212	1216	1219	1222	1225	1229	1232	1235	1239
1.33	1239	1242	1245	1248	1252	1255	1258	1261	1265	1268	1271
1.34	1271	1274	1278	1281	1284	1287	1290	1294	1297	1300	1303
1.35	1303	1307	1310	1313	1316	1319	1323	1326	1329	1332	1335
1.36	1335	1339	1342	1345	1348	1351	1355	1358	1361	1364	1367
1.37	1367	1370	1374	1377	1380	1383	1386	1389	1392	1396	1399
1.38	1399	1402	1405	1408	1411	1414	1418	1421	1424	1427	1430
1.39	1430	1433	1436	1440	1443	1446	1449	1452	1455	1458	1461
1.40	0.1461	1464	1467	1471	1474	1477	1480	1483	1486	1489	1492
1.41	1492	1495	1498	1501	1504	1508	1511	1514	1517	1520	1523
1.42	1523	1526	1529	1532	1535	1538	1541	1544	1547	1550	1553
1.43	1553	1556	1559	1562	1565	1569	1572	1575	1578	1581	1584
1.44	1584	1587	1590	1593	1596	1599	1602	1605	1608	1611	1614
1.45	1614	1617	1620	1623	1626	1629	1632	1635	1638	1641	1644
1.46	1644	1647	1649	1652	1655	1658	1661	1664	1667	1670	1673
1.47	1673	1676	1679	1682	1685	1688	1691	1694	1697	1700	1703
1.48	1703	1706	1708	1711	1714	1717	1720	1723	1726	1729	1732
1.49	1732	1735	1738	1741	1744	1746	1749	1752	1755	1758	1761

Table VII. (Con't.)

Four Place Logarithms.

	0	1	2	3	4	5	6	7	8	9	10
1.50	0.1761	1764	1767	1770	1772	1775	1778	1781	1784	1787	1790
1.51	1790	1793	1796	1798	1801	1804	1807	1810	1813	1816	1818
1.52	1818	1821	1824	1827	1830	1833	1836	1838	1841	1844	1847
1.53	1847	1850	1853	1855	1858	1861	1864	1867	1870	1872	1875
1.54	1875	1878	1881	1884	1886	1889	1892	1895	1898	1901	1903
1.55	1903	1906	1909	1912	1915	1917	1920	1923	1926	1928	1931
1.56	1931	1934	1937	1940	1942	1945	1948	1951	1953	1956	1959
1.57	1959	1962	1965	1967	1970	1973	1976	1978	1981	1984	1987
1.58	1987	1989	1992	1995	1998	2000	2003	2006	2009	2011	2014
1.59	2014	2017	2019	2022	2025	2028	2030	2033	2036	2038	2041
1.60	0.2041	2044	2047	2049	2052	2055	2057	2060	2063	2066	2068
1.61	2068	2071	2074	2076	2079	2082	2084	2087	2090	2092	2095
1.62	2095	2098	2101	2103	2106	2109	2111	2114	2117	2119	2122
1.63	2122	2125	2127	2130	2133	2135	2138	2140	2143	2146	2148
1.64	2148	2151	2154	2156	2159	2162	2164	2167	2170	2172	2175
1.65	2175	2177	2180	2183	2185	2188	2191	2193	2196	2198	2201
1.66	2201	2204	2206	2209	2212	2214	2217	2219	2222	2225	2227
1.67	2227	2230	2232	2235	2238	2240	2243	2245	2248	2251	2253
1.68	2253	2256	2258	2261	2263	2266	2269	2271	2274	2276	2279
1.69	2279	2281	2284	2287	2289	2292	2294	2297	2299	2302	2304
1.70	0.2304	2307	2310	2312	2315	2317	2320	2322	2325	2327	2330
1.71	2330	2333	2335	2338	2340	2343	2345	2348	2350	2353	2355
1.72	2355	2358	2360	2363	2365	2368	2370	2373	2375	2378	2380
1.73	2380	2383	2385	2388	2390	2393	2395	2398	2400	2403	2405
1.74	2405	2408	2410	2413	2415	2418	2420	2423	2425	2428	2430
1.75	2430	2433	2435	2438	2440	2443	2445	2448	2450	2453	2455
1.76	2455	2458	2460	2463	2465	2467	2470	2472	2475	2477	2480
1.77	2480	2482	2485	2487	2490	2492	2494	2497	2499	2502	2504
1.78	2504	2507	2509	2512	2514	2516	2519	2521	2524	2526	2529
1.79	2529	2531	2533	2536	2538	2541	2543	2545	2548	2550	2553
1.80	0.2553	2555	2558	2560	2562	2565	2567	2570	2572	2574	2577
1.81	2577	2579	2582	2584	2586	2589	2591	2594	2596	2598	2601
1.82	2601	2603	2605	2608	2610	2613	2615	2617	2620	2622	2625
1.83	2625	2627	2629	2632	2634	2636	2639	2641	2643	2646	2648
1.84	2648	2651	2653	2655	2658	2660	2662	2665	2667	2669	2672
1.85	2672	2674	2676	2679	2681	2683	2686	2688	2690	2693	2695
1.86	2695	2697	2700	2702	2704	2707	2709	2711	2714	2716	2718
1.87	2718	2721	2723	2725	2728	2730	2732	2735	2737	2739	2742
1.88	2742	2744	2746	2749	2751	2753	2755	2758	2760	2762	2765
1.89	2765	2767	2769	2772	2774	2776	2778	2781	2783	2785	2788
1.90	0.2788	2790	2792	2794	2797	2799	2801	2804	2806	2808	2810
1.91	2810	2813	2815	2817	2819	2822	2824	2826	2828	2831	2833
1.92	2833	2835	2838	2840	2842	2844	2847	2849	2851	2853	2856
1.93	2856	2858	2860	2862	2865	2867	2869	2871	2874	2876	2878
1.94	2878	2880	2882	2885	2887	2889	2891	2894	2896	2898	2900
1.95	2900	2903	2905	2907	2909	2911	2914	2916	2918	2920	2923
1.96	2923	2925	2927	2929	2931	2934	2936	2938	2940	2942	2945
1.97	2945	2947	2949	2951	2953	2956	2958	2960	2962	2964	2967
1.98	2967	2969	2971	2973	2975	2978	2980	2982	2984	2986	2989
1.99	2989	2991	2993	2995	2997	2999	3002	3004	3006	3008	3010

Table VII. (Con't.)

Four Place Logarithms.

	0	1	2	3	4	5	6	7	8	9	10	Interpolations 1	2	3	4	5
2.0	0.3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	3222	2	4	6	8	11
2.1	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	3424	2	4	6	8	10
2.2	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	3617	2	4	6	8	10
2.3	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	3802	2	4	5	7	9
2.4	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	3979	2	4	5	7	9
2.5	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	4150	2	3	5	7	9
2.6	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	4314	2	3	5	7	8
2.7	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	4472	2	3	5	6	8
2.8	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	4624	2	3	5	6	8
2.9	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	4771	1	3	4	6	7
3.0	0.4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	4914	1	3	4	6	7
3.1	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	5051	1	3	4	6	7
3.2	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	5185	1	3	4	5	7
3.3	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	5315	1	3	4	5	6
3.4	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	5441	1	3	4	5	6
3.5	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	5563	1	2	4	5	6
3.6	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	5682	1	2	4	5	6
3.7	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	5798	1	2	3	5	6
3.8	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	5911	1	2	3	5	6
3.9	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	6021	1	2	3	4	6
4.0	0.6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	6128	1	2	3	4	5
4.1	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	6232	1	2	3	4	5
4.2	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	6335	1	2	3	4	5
4.3	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	6435	1	2	3	4	5
4.4	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	6532	1	2	3	4	5
4.5	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	6628	1	2	3	4	5
4.6	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	6721	1	2	3	4	5
4.7	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	6812	1	2	3	4	5
4.8	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	6902	1	2	3	4	4
4.9	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	6990	1	2	3	4	4
5.0	0.6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	7076	1	2	3	3	4
5.1	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	7160	1	2	3	3	4
5.2	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	7243	1	2	2	3	4
5.3	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	7324	1	2	2	3	4
5.4	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	7404	1	2	2	3	4
5.5	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	7482	1	2	2	3	4
5.6	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	7559	1	2	2	3	4
5.7	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	7634	1	2	2	3	4
5.8	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	7709	1	1	2	3	4
5.9	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	7782	1	1	2	3	4

Table VII. (Con't.)

Four Place Logarithms.

	0	1	2	3	4	5	6	7	8	9	10	Interpolations 1	2	3	4	5
6.0	0.7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	7853	1	1	2	3	4
6.1	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7924	1	1	2	3	4
6.2	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	7993	1	1	2	3	3
6.3	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	8062	1	1	2	3	3
6.4	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	8129	1	1	2	3	3
6.5	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	8195	1	1	2	3	3
6.6	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	8261	1	1	2	3	3
6.7	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	8325	1	1	2	3	3
6.8	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	8388	1	1	2	3	3
6.9	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	8451	1	1	2	3	3
7.0	0.8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	8513	1	1	2	2	3
7.1	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	8573	1	1	2	2	3
7.2	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	8633	1	1	2	2	3
7.3	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	8692	1	1	2	2	3
7.4	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	8751	1	1	2	2	3
7.5	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	8808	1	1	2	2	3
7.6	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	8865	1	1	2	2	3
7.7	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	8921	1	1	2	2	3
7.8	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	8976	1	1	2	2	3
7.9	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	9031	1	1	2	2	3
8.0	0.9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	9085	1	1	2	2	3
8.1	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	9138	1	1	2	2	3
8.2	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	9191	1	1	2	2	3
8.3	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	9243	1	1	2	2	3
8.4	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	9294	1	1	2	2	3
8.5	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	9345	1	1	2	2	3
8.6	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	9395	1	1	2	2	3
8.7	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	9445	0	1	1	2	2
8.8	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	9494	0	1	1	2	2
8.9	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	9542	0	1	1	2	2
9.0	0.9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	9590	0	1	1	2	2
9.1	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	9638	0	1	1	2	2
9.2	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	9685	0	1	1	2	2
9.3	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	9731	0	1	1	2	2
9.4	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	9777	0	1	1	2	2
9.5	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	9823	0	1	1	2	2
9.6	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	9868	0	1	1	2	2
9.7	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	9912	0	1	1	2	2
9.8	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	9956	0	1	1	2	2
9.9	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996		0	1	1	2	2

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